A Study of Undergraduates' Understandings of Key Chemical Ideas in Thermodynamics

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Abstract

The purpose of this research study is to identify and classify chemistry undergraduates' misunderstandings of thermodynamic ideas in physical chemistry such as internal energy, enthalpy, entropy and Gibbs energy, together with the sources of these misunderstandings. For this purpose, questionnaires and semi-structured interviews were used to gather data both before and after the teaching of these topics.

Third year undergraduate students who took the physical chemistry course from two different chemistry education departments in Turkey, together with lecturers who deliver the course, took part in the study. In total, ninety-one students completed the pre-tests and post-tests. The pre-interviews were carried out with twenty-two students and twenty-seven students participated in the post-interviews. Two lecturers were also interviewed after the post-test.

The results revealed thirty nine common misunderstandings including some identified in earlier studies, fourteen were related to internal energy and associated ideas, twelve were related to enthalpy, six were related to entropy and seven were related to Gibbs energy. Many other less prevalent (less than 5% of students) misunderstandings were also found..

Eight different sources were identified from which the misunderstandings originated. There were (a) lack of knowledge of fundamental thermodynamic ideas, (b) application of algorithms without conceptual understanding, (c) using thermodynamic data to explain situations involving kinetics, (d) memorisation of scientific laws and statements without understanding, resulting in inappropriate over-generalisation (e) confusion of fundamental ideas, (f) explaining fundamental ideas according to their usage in everyday language, (g) the effects of everyday experiences, and (h) socio-economic and methodological aspects of the teaching and learning environment.

The findings of this study provide lecturers and tutors with information which will be of help in designing more effective materials and strategies for the teaching of thermodynamic ideas in physical chemistry.

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Chapter 1

Chapter 1

Introduction

> *Knowledge is not a copy of reality. To know an object, to know an event, is not simply to look at it. To know an object is to act on it. To know is modify, to transform the object, to understand the process of this transformation, and as consequence to understand the way the object is constructed.*
>
> *Jean Piaget (1964, p.176)*

Ever since the classical studies of Piaget, there has been an interest in the conceptions of physical science held by young children (Osborne and Wittrock 1983). Even a casual observer of the field of science education over the last two decades knows that this has been a period of unprecedented exposure of the ideas held by children, adolescents, and to a lesser extent adults, about a wide range of scientific phenomena (Griffiths 1994). Several thousand research studies have been published in all including over one hundred revealing students' ideas in chemistry. These data, collected by Pfundt and Duit (1998), have now reached 4500 entries. Research in this domain has attempted to answer questions such as which misunderstandings occur, what is their origin, how extensive are they and, of course, what can be done about them? (Gil-Perez and Carrascosa 1990).

It is quite understandable why students' ideas concerning chemical phenomena have become a research focus. Many students from all levels, from secondary level to university, struggle to learn chemistry and many do not succeed (Nakhleh 1992). Research now shows that many students do not correctly understand fundamental concepts (Griffiths 1994) and also many of the scientifically incorrect ideas held by the students go unchanged from the early years of the schooling to university, even up to adulthood (Gil-Perez and Carrascosa 1990). By not fully and appropriately understanding fundamental concepts, many students have trouble understanding the more advanced concepts that build upon these fundamental concepts (Thomas 1997).

Many high school and university students experience difficulties with fundamental thermodynamic ideas in chemistry (Banerjee 1995). Despite the importance of thermodynamics as the foundation of chemistry, most students emerge from introductory courses with only very limited understanding of this subject (Ochs 1996). The physical chemistry course, where students tackle more advanced ideas of thermodynamics and kinetics, is perceived by many students to be one of their most difficult courses (Thomas 1997).

Physical chemistry is composed of three broad areas. The distinction between these areas had been done by Atkins (1997) as quoted below:

> *Physical Chemistry establishes and develops the principles that are used to explain and interpret the observations made in the other branches of chemistry. Physical chemistry is characterised by three main approaches: the discussion of bulk properties in terms of thermodynamics, the use of spectroscopy to explore the behaviour of individual atoms and molecules, and the analysis of the rates and mechanisms of chemical change (Atkins 1997, p. 1).*

In this definition, Atkins makes three main divisions which are "equilibrium", "structure", and "change". Equilibrium is mainly contained by chemical thermodynamics, structure is contained in quantum mechanics and spectroscopy, and change is the main domain of chemical reaction.

Thermodynamics is fundamental to physical science and the concept of energy and the distinction between intensive and extensive properties contribute to many domains in physical science (Linn and Songer 1991). Thermodynamics is the key to chemistry, physics and all natural sciences. Therefore, if we grasp its essence then we will be able to understand the concepts and principles and apply them in our daily lives, for example: conservation of energy in our houses, maintenance of body temperature, cooking with microwaves etc., and we also can realise human behaviour in terms of being free and rich (Nordholm 1997). Thermodynamics is a fundamental subject in the university level courses especially in engineering and also in chemistry and physics. Thus, it is important to probe students' understanding capabilities in physical chemistry and their problems with grasping and applying the principles of thermodynamics to their everyday lives in terms of the development of industry and standards of human life. Perhaps the most important point is that the students who are the subject of this study will be chemistry teachers when they graduate. Their understanding of the fundamental thermodynamic ideas is crucial in terms of educating tomorrow's generations.

Chemistry had been regarded as a difficult subject for students by many researchers, teachers and science educators (Carter and Brickhouse 1989, Nakhleh 1992 and Anderson *et al* 1999) because of the abstract nature of many chemical concepts, teaching styles applied in class, lack of teaching aids and the difficulty of the language of chemistry. All these cause students, from primary level to the university, to develop poor understanding and misunderstandings. Misunderstandings have been attracting more attention over the last three decades (Villani 1992, Skelly 1993, Ayas and Demirbaş 1997). A number of studies have been conducted on different topics in chemistry (see for a review

Griffiths 1994, Garnett *et al* 1995), and in other areas such as biology, physics, or in general, in science (Driver 1981, Gilbert and Watts 1983, Duit 1987, Gil-Perez and Carrascosa 1990).

My interest in students' misunderstandings developed from my teaching experiences in the physical chemistry laboratory and tutorial courses as a teaching assistant. When I asked students to solve numerical problems they could solve these by using some algebraic methods, but most of them were unaware of the understanding behind the problems. This was similar to the findings of the study by Sawrey (1990). An examination of studies about students' understanding of basic physico-chemical ideas clearly demonstrates that most of the basic ideas were poorly understood or misunderstood (Thomas 1997, Banerjee 1996). Students' understandings of fundamental ideas associated with chemical thermodynamics have not yet been the subject of educational research, especially at a more advanced level beyond the general chemistry (Thomas 1997). Relatively little research has been conducted at the tertiary level about students' understandings of entropy and Gibbs energy (Granville 1985, Beal 1994, Riberio *et al*1990, Selepe and Bradley 1997). More research needs to be done to identify what sort of difficulties students face in the understanding of physico-chemical ideas. Misunderstandings are important for learning therefore they are important for teaching. Both science educators and cognitive researchers mainly agree that efforts to understand and improve science education should be focussed on fundamentally important knowledge domains (Linn and Songer 1991). Hence, it has been concluded that it is worthwhile to conduct a research study about chemistry undergraduates' misunderstanding of fundamental thermodynamic ideas which are a part of the physical chemistry courses, and factors which may give rise to these misunderstandings.

1.1 The Purpose of the Research and the Research Questions

The purpose of this research is to identify and classify the chemistry undergraduates' misunderstanding of thermodynamic ideas in physical chemistry such as internal energy, enthalpy, entropy and Gibbs energy, together with the sources of these misunderstandings. For this purpose, questionnaires and semi-structured interviews, before and after teaching, were used. To enhance the generalisation of the study, students from two different universities in Turkey had been chosen. The findings of this study were intended to be used to develop an effective teaching methods to improve students' learning abilities in physical chemistry.

Misunderstandings may occur in students' understanding of scientific knowledge. The identification of students' misunderstandings has the potential to improve teaching and learning. It has the capacity to inform curriculum processes and help teachers guide students in the construction of meaning which is closer to that 'agreed' by the scientist (Garnett *et al* 1995). Therefore, the first research question comes out as:

- *"What are the third year Turkish chemistry undergraduates' misunderstandings about internal energy, enthalpy, entropy and Gibbs energy?"*

Misunderstandings may be rooted in various sources including everyday life experiences, different instruction and learning styles, language, cultural and religious views, curriculum and nature of the subject matter. Hence, it is important to reveal the sources of misunderstandings before taking any further action to correct them. Therefore, the second research question is:

- *"Where do these misunderstandings arise? What are their sources?"*

Once the misunderstandings and their sources are identified it should be followed by the solution to the problem. In this study only some recommendations, in the light of the literature, will be given to help tackle the misunderstandings. In the next section the Turkish education system and chemistry in the curriculum will be explained.

1.2 The Turkish Education System and Chemistry in the Curriculum

After the collapse of the Ottoman Empire, a new republic called Turkey was established in 1923. Turkey, with a population of 63 million, is a bridge between Europe and Asia. A short time after the proclamation, to change the poor and less developed appearance of the country, many innovations were undertaken in all areas, including education (Ayas *et al* 1993). The Turkish Educational system was centralised by the 'Act of Law of Unification of Instruction' in 1924. The Ministry of Education covers all the educational institutions except universities. All schools throughout the country have to use the same curricula, which are developed and implemented by the Ministry of Education.

Schooling consists of three main components in Turkey. These are eight years of compulsory primary education, between ages 6-14; three years of secondary education, between ages 14-17; and higher education, colleges and universities (Ayas and Demirbaş, 1997). The universities are partly controlled by The Higher

Education Council of Turkey (YÖK).

Chemistry topics are first introduced to students in the fourth grade (10-11 years) in science courses in the Turkish Primary Science Curriculum. The first topic students come across is introduction of matter and then it is followed by matter and energy in the fifth grade (11-12 years). Heat is introduced both at fifth and seventh grades in primary science curriculum. At the beginning, heat is defined and some sources of heat are explored and in the seventh grade the heat and temperature relationship is introduced. The structure of matter is handled in the eight grade (14-15 years) (MEB,1992).

In the secondary school (grades 9-12, 14-17 years) chemistry is taught as a separate subject. In the first year (grade 9), the phases of matter, chemical reactions, theories of atom, periodic table and radioactivity are delivered. In the second year (grade 10), thermochemistry, the rates of chemical reactions (kinetics), the equilibrium in chemical reactions, dissolving, acid and bases , and redox reactions are taught. The chemical bonds and basic organic chemistry which includes hydrocarbons, alcohols, and ethers, aldehydes and ketones, carboxylic acids and their derivates, aromatic compounds are introduced in the final year (grade 11) of the secondary school chemistry curriculum. (MEB, 1992)

1.3 Definition of Terms

It has been reported that there are over twenty different names used in literature for students' misunderstandings (Millar 1989). The most commons are misconceptions (Hackling and Garnett 1985, Gil-Perez and Carrascosa 1990), children's ideas (Gilbert *et al* 1982), alternative conceptions (Garnett *et al* 1995, Thomas 1997), and alternative frameworks (Driver 1981). There is general agreement that the word '*misconceptions*' has been used inappropriately in research in this area (e.g. Gunstone, 1989). In this study, therefore, the term *misunderstanding* is used. The term *misunderstanding* refers to an idea that it is scientifically incorrect or unacceptable. In addition, there is also little agreement among the experts about the definition of '*concept*'. In general it is used synonymously with *idea* (Herron *et al* 1977). However, the word '*concept*' is more appropriately applied to a fundamental idea which underpins much of the knowledge and understanding in a subject. In chemistry such 'concepts' might be *chemical change*, *conservation of mass*, *the particular nature of matter.* Because of the disagreement among the experts about the definition and use of the term '*concept*', in this study, the term '*idea*' is used. It refers to the chemical terms such as internal energy, enthalpy, entropy and Gibbs energy. A comprehensive review and discussion of the use of terminology about misunderstandings throughout the literature may be heard in section 2.2. Moreover, the term '*respondents*' refers to the students who completed the questionnaire. Also the term '*response*' refers to the whole answer given for a single question in questionnaires.

1.4 A Summary of the Forthcoming Chapters

In this section, the content of the following chapters will be summarised.

Chapter 2 reviews the studies carried out on concept learning in science. These include students' ideas and misunderstandings about basic thermo-chemical ideas such as kinetic molecular theory, heat, temperature, work, internal energy, enthalpy, entropy and Gibbs energy. This chapter also reveals the approaches used to elicit information about students understanding of selected ideas and the techniques used to overcome the students' difficulties.

The methodology chapter, Chapter 3, describes how the research was planned and designed. It outlines the research procedures applied, the aspects of the physical chemistry course in the participant universities, and how the research instrument was planned and developed including the use of pilot studies. The data collection and analysis issues are explored as well. Moreover, it describes how the interviews were conducted and the results were analysed. The strengths and weaknesses of the data collection techniques are discussed along with alternate data collection tools available. Finally, the limitations of the data collection are addressed and the validity and reliability of the data collection and data analysis are discussed.

Chapters 4, 5, 6 and 7 present the data obtained in the research study related to internal energy and related ideas, enthalpy and related ideas, entropy and related ideas and Gibbs energy and related ideas respectively. In each chapter, the responses given to the related questions were analysed and the results presented. The students' misunderstandings were identified and their possible sources are focussed. The results which emerged from the interviews are also presented. The chapters include tables which summarise the results related to each question. A summary of the results obtained in the related chapters are included.

Chapter 8, which is the last of the five chapters presenting data obtained in the research study, explores the students and lecturers views of learning difficulties which students experience in the physical chemistry course and possible solutions are proposed by the students and lecturers.

The final chapter, Chapter 9, gives a summary of the students' misunderstandings found in the research study and outlines the possible sources of these misunderstandings. Finally, the implications for better teaching of the thermodynamic ideas in chemistry are reviewed.

Chapter 2

Chapter 2

Students' Misunderstandings in Physical Chemistry:

A review of literature

The literature review explores the studies of students' understanding of the basic thermodynamics ideas. The study focuses on the university students' misunderstandings in physical chemistry and it is therefore important to ascertain students' existing level of knowledge. This was done in three ways.

Firstly, the studies conducted on concept learning in science, including students' misunderstandings, are reviewed. Students' conceptual development and their understanding of the scientific concepts are essential to develop meaningful explanations of their difficulties. In order to overcome their conceptual understanding difficulties, the sources of the problems should be recognised. For this purpose, studies about students' concept learning in science, definitions and the features of the misunderstandings along with the common misunderstood topics in chemistry are reviewed.

Secondly, the review provides an insight into the studies of both students' understanding and misunderstandings in kinetic theory and basic chemical thermodynamic concepts. Much work to date has explored students' ideas on thermodynamic concepts, such as heat and temperature, however, there is little research at an advanced level. Kinetic theory was chosen because it is central in explaining many thermochemical phenomena. In subsequent sections, studies on students' ideas and misunderstandings about chemical energy, work, internal energy, enthalpy, entropy, Gibbs energy and spontaneity are reviewed. These sections establish aspects of the basic physical chemistry and help focus the study towards the areas most suitable for investigation.

Finally, approaches used to elicit information about students' understanding of certain concepts and implementations to overcome difficulties are explored. In each section, although a number of methods have been employed, these are not explicitly reviewed. They will be a central strategy to develop the solutions to the problems for the proposed study. The difficulties and the proposed implementations are also reviewed. The chapter begins by discussing the term 'concept' and concept learning.

2.1 Concept and Concept Learning in Science

Giving a precise definition of the term *concept* is not easy. In the literature, there are a number of definitions, each of them reflecting different aspects of it. Martorella *et al* (1972) defines concept as:

> *A concept is a general idea, usually expressed by a word, which represents a class or group of things or actions having certain characteristics in common* (p.2).

Although it may be impossible to give an exact definition, educationalists have different definitions for the term *concept*. Kean (1982) suggests that a concept will be taken to be a set of specific objects, symbols, or events that may be grouped into a class on the basis of shared attributes; the set must be referenced by a class name or symbol. She also suggests that a concept should be classified according to its' hierarchical relationship, because some concepts are more fundamental than others. Additionally, related concepts bear a coordinate relationship to one another.

Cognitive aspects of concept learning are complex processes in which researchers have been taking great interest for a number of decades, and hundreds of studies have been done. The section begins by explaining the differences between *development* and *learning* according to Jean Piaget, who undertook several detailed studies on children's development and learning progress. According to Piaget:

> *.... development is a process which concerns the totality of structures of knowledge. Learning presents the opposite case. In general, learning is provoked by situations- provoked by a psychological experimenter; or by a teacher, with respect to some didactic point; or by an external situation ... so ... development explains learning, and this opinion is contrary to the widely held opinion that development is a sum of discrete learning experiences.(Piaget 1964, p. 176)*

Piaget describes intellectual development in terms of four stages. Those well known stages are:

- *Sensory- motor, which appears 18 months after birth, and in this stage the child develops the practical knowledge that constitutes the substructure of later representational knowledge.*
- *Pre-operation in which a child begins to learn language and some symbols and representations.*
- *Concrete operation (or first operation) in which operating on objects such as classification, ordering of numbers starts.*
- *Formal (or hypothetic-deductive) operation is the last stage in intellectual development In this stage, a child constructs new operations of propositional logic, namely the operations of classes, relations, and numbers (p.177).*

Although Piaget's intellectual development stages are generally accepted, there are a number of diverse views especially about the last stage (formal operation), where students would expect to be at the formal operation stage, but are not. According to Piaget, students enter the formal operation stage at the age of 12 and complete their basic intellectual development by the age 15, but Herron

(1975) reports that a number of studies show that students from England, Australia and America do not complete their formal operation stage by the expected age. In addition, Novak (1984) argues that Piagetian cognitive development theory has only limited relevance to learning in school. In his opinion, Ausubel's cognitive learning theory is more useful to improve science instruction because of its simplicity in a number of key concepts and its comprehensiveness in terms of the school learning events. He summarises Ausubel's cognitive learning theory in seven headings. These are: meaningful learning which is the central idea, rote learning, subsumption, progressive differentiation, superordinate learning, integrative reconciliation and advance organiser. According to Ausubel:

> *meaningful learning involves the acquisition of new meanings, and new meanings, conversely, are the products of meaningful learning. That is, the emergence of new meanings in the learner reflects the completion of a meaningful learning process (Ausubel 1968, p.37).*

Novak (1984) described Ausubel's meaningful learning theory as nonarbitrary, substantive, non-verbatim incorporation of new knowledge into cognitive structure which forms the framework of knowledge stored in our minds (Novak 1984). In contrast, rote learning is the opposite of meaningful learning. When students incorporate new information into cognitive structure in an arbitrary, verbatim, non-substantive way, it is called rote learning.

The learning of science concepts has been widely studied during the last two decades. The main concerns are understanding and overcoming students' misunderstandings, developing effective teaching methods, supplying new teaching instruments and milieu to enhance the science teaching. Understanding science is particularly important at present, because of the existing technological developments and associated opportunities such as space studies, studies in computer science, gene technologies, nuclear energy etc. No-one can isolate themselves from contact with the social and physical milieu where individuals live and everyone acquires considerable knowledge about the natural and technological worlds around them. Therefore, science teaching has a greater importance at present than ever.

Students' difficulties in learning and applying scientific concepts are caused by fragmented and incorrectly interpreted knowledge (Labudde *et al* 1988). These difficulties were categorised as follows:

> *a knowledge base that is fragmented, incoherent and prone to misconceptions; unsystematic or inefficient search and retrieval process; an inability to apply knowledge appropriately after it has been retrieved; and, failure to distinguish between concepts and reasoning modes used in science versus those used in everyday life (p.81).*

They also argue that using the common styles of teaching used in science, such as introducing scientific concepts by verbal or mathematical definitions and without making explicit connections with students' previous conceptions, contribute to students' conceptual difficulties.

Osborne and Wittrock (1983) studied science learning by applying a generative learning model which describes it as a process of constructing meaning which is influenced by students' prior conceptions. Their thesis was that '*children develop ideas about their world, develop meanings for words used in science and develop strategies to obtain explanations for how and why things behave as they do, long before they are formally taught science* (p.491)'. Students' views sometimes could be subtly and dramatically different from those of a scientist and from the ideas taught in science lessons. Therefore, they suggest that a change in approach to science education is required and they emphasise the importance of curriculum design and teaching styles for science. Finally, they affirm that when a teacher gives an explanation of how and why something behaves as it does, the pupil must actively create meaning from that explanation and must link those meanings to other ideas in their memory in order to achieve successful learning.

There is a growing interest among science educators in the use of the Piagetian learning cycle for teaching abstract scientific concepts (Batt 1980). Other researchers, such as Howe (1996), pay attention to Vygotsky's work on the development of scientific concepts in childhood. Vygotsky, a psychologist and a contemporary of Piaget , was interested in some of the same learning problems as Piaget, but their approaches were different. Howe (1996) distinguishes as follows;

> *Piaget, as an epistemologist, seeking the origin of knowing; Vygotsky, as a psychologist, seeking the origin of consciousness. There were many points of agreement between them; both were constructivists in the sense that they believed that each individual constructs his or her own knowledge and meaning and both believed that children's thinking is constrained because certain higher intellectual functions, including awareness of mental operations, are not available until adolescence. On other points Vygotsky disagreed with Piaget and challenged his theoretical position on certain aspects of child development (p.37)*

According to Vygotsky there are two kinds of concepts; *everyday concepts* and *scientific concepts.* Everyday concepts come from a child's experience and independent thinking, where those concepts learned in school are called scientific concepts. Piaget, on the other hand, distinguishes those concepts as *spontaneous* and *non-spontaneous* (Howe 1996). As a result, Howe concluded that it was time to broaden our vision of how children learn science and to incorporate a socio-cultural perspective in research, teaching, and curriculum development that is derived from Vygtsky's work but not constrained by it.

In order to develop effective science teaching some researchers focussed on promotion of critical thinking . Zoller (1987) tried to implement students' critical thinking in class and found that it was more effective than the traditional teaching methods in chemistry. Recently, Kogut (1996) took into account students' intellectual development and the extent of conceptual knowledge. He observed that student skills in critical thinking would improve if an environment were created that provided practice and encouragement.

Another researcher, Dunn (1983), investigated the influence of instructional methods on concept learning. She designed six instructional methods and implemented them on college students. These were discovery, expository(A), expository(B), prototype development, interrogatory and combination method which was a combination of the prototype development and interrogatory methods. As a result, Dunn stated that *'if a high level of concept attainment is desired, or if a concept has many variable attributes, either the prototype developmental method alone should be considered as instructional methods which may be more effective than the discovery method or traditional expository lessons'* (p.655). Moreover, Stepans *et al* (1988) examined ways of teaching science by comparing the effectiveness of the expository teaching model and the learning cycle approach to bring about a valid understanding of science concepts in prospective elementary teachers. The expository teaching model consists of lectures, demonstrations conducted by teachers and written problems given to the students to encourage them to take notes during the teaching. In conclusion, they suggest that college students' understanding of science concepts may be improved by using a teaching style that combines demonstration with lecture or the learning cycle model.

2.2 A Closer Look to the Terminology Used for Misunderstandings

Much attention has been paid to students' misunderstandings of fundamental scientific concepts during the last three decades. Although the main body of the research has been conducted during the past decade, Driver and Easley (1978) report that the studies of pupils' misunderstandings in science could be seen in Piaget's early studies of children's ideas.

Misunderstandings have been defined from different points of view and labelled differently throughout the different research articles. Rowell *et al* (1990) prefer to use 'misconception' and define it from the Piagetian point of view:

> *Misconceptions are constructions and the process of their construction are those of equilibration. Thus, like all explanatory knowledge, the construction of misconceptions starts with the recognition of a knowledge 'gap' of some kind. Dependent on what is already known, and on the range and sequence of experiences faced, including those contrived by teachers, construction continues with the creation of potentially gap-filling possibilities from which a selection is made, and often subsequently modified. The resulting knowledge, the misconception, is the 'best' the individual has managed to produce to that point in time, and is the starting point for any further progress irrespective of whether it is limited or wrong (p.168).*

Although Ausubel has not done research on misunderstandings, he mentions them as *'preconceptions'*. He signified their importance in the teaching of science to children, or adults by stating:

> *Anyone who has attempted to teach science to children, or to adults for that matter, is painfully aware of the potent role of preconceptions in inhibiting the learning and retention of scientific concepts and principles'* (p.336).

He also argued that preconceptions both inhibit the learning of new scientific concepts and principles, and the assimilation of new proposed ideas to replace them. Ausubel qualifies the misunderstandings as tenacious and resistant to change. Ausubel's co-worker Novak defines a general meaning of the term '*misconception*' in his meaningful learning theory.

> *Each culture has more or less common meaning for the word labels for concepts, but each individual's subsumers are in at least small ways idiosyncratic. In some instances, this idiosyncratic meaning departs widely from the culturally accepted meaning and we say the person has a 'misconception' or 'alternate framework'. Once established in cognitive structure these idiosyncratic subsumers are not easily modified (Novak 1983, p.101).*

Moreover, Driver *et al*, an influential group of researchers in science education, who has been working in the area for over two decades, labelled the term as '*alternate frameworks*' and defined both terms as follows:

> *misconceptions..., pupils have been exposed to formal models or theories and have assimilated them incorrectly. In such cases Ausubel's theory has been put forward as an explanatory device to interpret this kind of problem, in which it is suggested that pupils are relating new knowledge to existing knowledge and are making wrong connections. In such cases the focus is on the learning of theoretical element of instruction. It is problems of the alternate frameworks which arise from students' personal experience of natural events and their attempt to make sense of themselves, prior to instruction, on which ideographic studies mainly attempt to throw some light* (Driver and Easley 1978, p.68).

In this definition, they stressed the importance of the students' personal experience, because a student develops conceptual structures by combining instructions and their experiences. In addition to this, Herron(1990) divides misunderstandings into two categories in terms of their origins. According to him, one of these categories is that misunderstandings deal with what actually happens in the physical world such as students' beliefs that heavy objects always sink in water, that the bubbles seen in the boiling water are hydrogen or oxygen; that rapidly boiling water is at a higher temperature than gently boiling water etc. The other category of misunderstandings deal with students' explanations of what happens in the natural world, such as heat is substance that flows between bodies. Herron also indicates that those ideas, called misconceptions, are not misconceptions about what happens but alternative explanations. In some cases, the explanations might be quite logical from the students' point of view, since they are consistent with their understanding of the world and are resistant to change, but those explanations are not acceptable to the scientist.

One of the more easily understandable definitions for the term *misconception* comes from Nakhleh (1992). He uses the term misconception to mean any concept that differs from the commonly accepted scientific understanding of the term. Nakhleh advocates that once a misconception is integrated into a student's cognitive structure, new information cannot be connected appropriately to his/her cognitive structure and thus weak understanding or misconception occurs. Nakhleh also summarises the names used instead of the term 'misconception'. These are: *preconception*; *alternative frameworks*; *children's science*; *students' descriptive and explanatory systems*; and more recently *intuitive conception* and *naive conception* as reported by Skelly (1993). Skelly's definition for the term *misconception* is also an easily understandable one. '*A misconception is defined as a mental representation of a concept which does not correspond to currently held scientific theory*'(p.1498). However, Skelly indicates that misconceptions are not taught directly or intentionally, but result from an individual's understandings of meaning of a situation. In addition, Skelly divides misconceptions into two categories; *experimental misconceptions* which arise from life experience and *instructional misconceptions* which result from the instructional processes. The main principles of experimental misconceptions are that they are extremely resistant to change and that they have a basis in logic.

Instructional misconceptions are rooted in either a formal or an informal instructional situation. In a recent review by Skelly(1993), instructional misconceptions are examined in six headings in terms of their origins. Those are given as;

- *Language related misunderstanding and misinterpretation of vocabulary, analogies, symbols, or overall meaning.*
- *A deficient knowledge based on the part of the learner.*
- *Overtaxing the short term memory of the learner.*
- *A mismatch of the cognitive demands of the subject matter with the cognitive level of development of the learner.*
- *Choice of mental strategies inappropriate to the subject matter.*
- *Low standards of epistemology on the part of the student.*

Misunderstandings are defined differently by various writers. One of the writers, Bodner (1991), indicates that there are two additional sources of misunderstandings in chemistry. One of them results from terms used such as '*heat capacity*' and phrases such as '*heat flows*'. Bodner(1991) implies that the language remains constant as science evolves, while the meaning of the terms changes. The other source of the misunderstandings stems from the instructors, and Bodner(1991) called this '*instructor-driven*' which is caused because of the non-explicit instructions.

In this study, the term *misunderstanding* will be used rather than *misconception* to avoid the confusions reported in the literature. The term *misunderstanding* refers to an idea that it is scientifically incorrect or unacceptable. Now, common misunderstandings in chemistry revealed in the literature will be reviewed.

2.2.1 Commonly misunderstood topics in chemistry

Early studies on students' misunderstandings were focussed on theoretical aspects, and then descriptive studies which identify particular misunderstandings were conducted in science. Skelly (1993) reports that initially the vast majority of studies were in the area of physics with studies in chemistry accounting for less than 10%. There were even fewer in biology. According to Driver and Easley (1978), the early studies in chemistry started with Doran, who studied 7-12 year old students' misunderstandings in kinetic theory, and this was followed by Zarour's studies which were about high school and university students' misunderstandings in physics, earth science, chemistry and biology. A series of studies have been conducted in Scotland by Johnstone and his students on their difficulties in mole concept and thermodynamics. Their studies were based on 16 -18 year old chemistry students' misunderstandings in enthalpy, Gibbs energy and entropy. Subsequently, students' misunderstandings in chemistry were studied. Several research studies were conducted in a number of specific areas including the particular nature of matter, chemical equilibrium, acids and bases, physical and chemical change, combustion, electrochemistry, the nature of matter, chemical bonding, dissolving and solutions, stoichometry and thermodynamics (Griffiths 1994, Barker 1994). Although the vast majority of these studies were conducted in the age group 7-18, very few studies were done on university students (eg. Selepe and Bradley 1997, Banerjee 1995, Tomanek 1994). Little research has been done on university students' understanding of thermodynamics or other related ideas in physical chemistry such as kinetic theory of gases and behaviours of solids and liquids at the molecular level. Therefore, it was considered worthwhile to explore what university students' know about the physico-chemical ideas. The next section considers students' ideas and misunderstandings in these areas.

2.3 Students' Ideas and Misunderstandings About Kinetic Theory

Students' misunderstandings of the particulate nature of matter have been the focus of science education researchers during the last two decades. The particulate nature of matter is generally introduced to students in secondary school, around the age of 12, and continues to be developed in high school and university with an increasing complexity. However, secondary school students still find it difficult, a significant proportion of the university students display the same low level of understanding (Benson *et al* 1993). Chang (1994) suggests that the kinetic theory can be summarised in four main statements. These are:

- *all matter is made of discrete particles and gas molecules can be considered to be 'points'*
- *the space between the particles is empty*
- *particles are in constant random motion, and they frequently collide with one another*
- *the average kinetic energy of the molecules is proportional to the temperature of gas*

In the following sections, students' misunderstandings of the four main statements of the particulate nature of matter are tabulated and discussed in turn.

Table 2.1 Some identified misunderstandings about the particulate nature of matter

Misunderstandings identified	***Students' age***	***Revealed by***
• Matter is in a continuous (non-particulate phase	13-14 year old	Novick and Nussbaum (1978, 1981)
• There is no empty space between the particles.	Cross age from 8-10 to university	Benson *et al* (1993)
• Solids and liquids are in a continuous phase	14-15 year old	Stavy (1988)
• There are more particles, dirt, dust, germs, unknown particles, vapours and other gases such as oxygen and nitrogen between the particles.	13-14 year old	Novick and Nussbaum (1978,1981)
• Particles are held in space by attractive forces, air floats in space because of the its low specific gravity, each layer of air rests on the below it, there is no vacuum.	13-14 year old and university	Novick and Nussbaum (1978,1981

2.3.1 All matter is made of discrete particles

It is a difficult concept for students to grasp that all matter is made of discrete particles. Students at the lower grades generally think that matter is in a continuous (non-particulate) phase, and in subsequent classes, start using the particulate theory of matter with an insufficient knowledge. Barker (1995) expresses precisely that point as:

> *Children have difficulty in understanding that matter is made of particles for two main reasons. First, their naive view of matter focuses on what can be sensed directly, on the principle that 'seeing is believing'. The particulate theory is usually introduced through practical demonstrations which require a particle model for their explanation. This leads to the second problem. Students have already constructed a view of matter which does not include particles and which they have found effective, so they have no need for a particulate model of matter. This means that the new ideas being put across by the teacher clash with the way the child thinks (p.25).*

As Barker (1995) indicates, the main learning problem is that students feel that 'seeing is believing', and therefore teachers should be very careful when they teach in primary or junior high school because their students' previous ideas will affect their learning progress. Frequently students are not able to imagine the behaviour of the gas molecules in a container and a considerable proportion of the students think that gas molecules in a container are in a continuous phase.

Novick and Nussbaum (1978) interviewed 13-14 (8th grade) year old Israeli students to probe understanding of the students' ideas about the particulate nature of matter after teaching. They found that approximately 60% of the students used a particulate model to explain the various phenomena involving gases, but 21% of the students used a continuous model. They also investigated 8th grade students who learned about the particulate model in the 7th grade had internalised the basic aspects of the model related to gases. They expressed this as:

> *the learner must overcome immediate perceptions which lead him to a continuous, static view of the structure of matter. He must accommodate his previous naive view of the physical world so as to include a new model adopted by scientists. Internalising the model therefore overcoming basic cognitive difficulties of both a conceptual and perceptual nature (p.187).*

Moreover, Novick and Nussbaum (1981) attempted to find out how pupils' conception of matter changed as they grew older and as they were progressively exposed to additional relevant information in higher grades. A written test was administrated to a fairly large sample containing students from elementary school through to university. The test was designed to test the same ideas as their earlier studies, and they found similar results as their previous work that pupils differentially internalise aspects of scientific models. They also found from cross age comparison studies that cognitive difficulties were real and did not diminish with age. The university students had the same difficulties as junior or high school students but the proportion became less as the age increased (Novick and Nussbaum, 1981).

After Novick and Nussbaum (1981), Benson *et al* (1993) conducted similar research with a larger number of students ranging from grade 2-4 to university age. They tested the same ideas as Novick and Nussbaum (1981) with the aim of discovering students' preconceptions identifying the pre-existing ideas which may profoundly influence the students' ability to learn and understand. They made some changes to the test technique to make it less time consuming and they also used the interview technique to gather the data. Their results indicate findings very similar to those of Novick and Nussbaum (1981); that the lower grade students draw the gas as a continuous phase but this occurs less frequently in the higher grades. Although university students use the particulate representation of gases, they are not able to grasp the idea that there is a space between the particles. Finally, they concluded that students' drawings of the particulate nature of matter represent preconceptions, which are only changed when they feel that their existing views are unsatisfactory in some way.

In another study about children's ideas of gases, Stavy (1988) reports that the learning of new knowledge is a very slow and continuous process. At the beginning, students use a macroscopic description that gas is a form of matter. Then, they understand the particulate nature of matter and use this microscopic definition to explain the gaseous state. Stavy implies this by writing:

> *It is interesting to note that in spite of the fact that students are taught the particulate theory of matter in the seventh grade, none of the seventh grade students used this definition. Only 25% of the eight grade students and most of the ninth grade students did so (15% of the latter used a combination of the second and third level of definitions).Here too, a gap of two years exists between the time students are taught the particulate theory of gas (pp.558-559)*

On the other hand, students' ideas about solids and liquids are also quite different from the scientific ones. Driver *et al* (1994) define the students' ideas of the solid form of matter as an ordered arrangement of molecules and about 20% of pupils had a continuous (non-particulate) view at the age of 17. Students' ideas about the liquid phase are similar to the solid state in that liquids are continuous and static. Novick and Nussbaum (1978) found that, even after instruction on the kinetic theory, more than 10% of 13-14 year olds depict the particles of air as changed to continuous liquid phase when cooled. However, Stavy (1988) reports similar information on students' ideas about solid and liquid phases of matter in that, only about 25% of the students in ninth grade defined the concepts of solid and liquid by means of the particulate nature of matter. Additionally, about 15% of them explained the process of evaporation by means of this theory.

2.3.2 Space between the particles is empty

Students find it hard to understand that there is an empty space between particles. They imagine matter as continuous (non-particulate) and even the students who have grasped the particulate theory cannot imagine empty space between particles. Novick and Nussbaum (1978) showed that only 46% of the pupils who understood the particulate nature of matter clearly and spontaneously explained that there is empty space between particles. A further 16% were doubtful. Initially students' drawings showed more particles between the original particles, but after a further questioning, they accepted the existence of the empty spaces between particles. On the one hand students suggested that particles were discrete entities, on the other hand they offered the following explanations for them:

> *Dust and other particles; other gases such as oxygen and nitrogen; the particles are closely packed-there is no space between them; air, dirt, germs; may be a liquid; unknown vapours; no place is completely empty (Novick and Nussbaum 1978, p.276)*

Novick and Nussbaum (1981), asked the students what there was between the particles as drawn in an evacuated flask. About 40% of senior high and university students responded that 'pollutant' was present. However, the writers stressed that over 60% of the students, beyond junior high, did not picture empty space in a gaseous medium and this indicates that there is a persistent and widespread preconception of matter as essentially a continuous medium. Moreover, Nussbaum (1985) reports that students did not believe in the existence of a vacuum. He explains this as:

> *According to this notion 'nature abhors vacuum'. Therefore, if a vacuum is created momentarily it will immediately be 'filled' by nearby substances 'rushing in'. It is believed that the movement of these substances is caused by 'sucking force' originating in the vacuum (p.141).*

In contrast to the above studies, Séré's (1985) research on 11-12 year old students' knowledge about air, shows that nearly all of the children acknowledged that the temperature would not change in an empty container (a vacuum), even if the enclosure is heated. This indicates that students were aware of the vacuum, but according to Benson *et al* (1993), although about 70% of the university chemistry students have a particulate model of gases, about 33% of them did not show the empty space between particles in their drawings.

2.3.3 Particles are in constant motion

Gas particles are evenly distributed and exert pressure on the sides of the vessel because of their constant motion. Students have found this idea difficult to comprehend. In order to ascertain students' understanding of this , Novick and Nussbaum (1978) asked 13-14 year old students to picture air particles in a partially evacuated flask. A considerable proportion of the students drew air as a continuous phase around the sides of the evacuated flask, or in a mass at the bottom or top of the flask. However, some students drew the particles in clumps in the flask by explaining that air was composed of tiny particles and they were held by attractive forces. Some students drew air particles, but when they were asked 'why the air does not settle to the bottom of flask ?' they gave such answers that:

> *the particles want to rise; they are held in space by attractive forces; the particles weigh very little and therefore rise; air floats in space because of its low specific gravity ; each layer of air rests on the one below it; if all the particles fell to the bottom, there would be a vacuum and this is impossible; since there are many particles they take up all the space and do not fall (Novick and Nussbaum 1978, p.277).*

In another study Novick and Nussbaum (1981) found that senior high school and university students showed a spontaneously uniform distribution of air particles, but their answers to the question 'why do the particles not fall to the bottom of flask ?' were that particles were in constant motion. Only 20% of them explained that there were repulsive forces between particles. In addition, Stavy (1988) did similar research to Novick and Nussbaum, and found that only 5% of 8th and 9th grade students mentioned the attraction forces between particles. Recently, Benson et al (1993) showed that 85% of university students made particulate drawings, but only 37% showed a diffused arrangement of the gas molecules.

Finally, Barker (1995) summarised the students' difficulties with movement of the particles in a gas. She wrote:

> *Both the attractive and repulsive force ideas imply that the particles are static, suggesting that the movement of particles in a gas is a most difficult notion to learn. The attractive forces idea supports the 'clumped together' model, while the notion of repulsive forces is used to explain uniform distribution of particles (p.28).*

2.3.4 The average kinetic energy of the molecules is proportional to the temperature of the gas

There is a limited amount of research covering the teaching aspects of the average kinetic energy of molecules. The studies about kinetic energy of gases are mainly based on algebraic problems. They emphasise that students who memorise the postulates of the kinetic theory of gases can solve the problems easily, but they cannot understand the idea of the gaseous behaviour. In order to achieve the conceptual understanding of the kinetic energy, rms (root mean square) speed and the frequency of particles which collide in a vessel with both each other and walls of the vessel, Cornely-Moss (1995) developed a series of quiz questions which can be completed by general chemistry students in about ten minutes. Cornely-Moss insists that this is a useful starting point to prevent the students' misunderstandings in the kinetic theory of gases.

2.3.5 A summary of students' misunderstandings about kinetic theory

The reviewed studies show that a considerable proportion of the students have difficulty in internalising important aspects of the kinetic theory. Firstly, a significant proportion of the students perceive the air or gases as continuous, therefore they cannot give meaningful explanation to their behaviour. Novick and Nussbaum (1978) argue that:

> *Before introducing the particle model, much stress is placed on the bulk properties of gases (even though they are invisible) they have weight; they flow; they exert pressure... this stress may be more difficult for many pupils to really accept the idea of empty space in their particle model (p.280).*

Secondly, some students confuse the particulate theory in solids and liquids because of their relative rigidities compared with the gas phase. The students were able to apply several aspects of the particulate theory into the gaseous state, but not in solid and liquid states. Students were not able to grasp the ideas of empty space, motion and interaction between the particles in the solid and liquid phase.

Finally, it is important to recognise that students' ideas may change if they are presented with demonstrations using colourful gases. Otherwise, it is difficult to grasp the idea behind the kinetic theory of gases because of its abstract nature, especially for students in the lower grades.

2.4 Students' Ideas and Misunderstandings About Chemical Thermodynamics

Thermodynamics is fundamental to much of the physical science. The concept of energy and the distinction between intensive and extensive properties contribute to many domains in the physical science. Because of its importance in understanding life and its abstract nature, hundreds of studies have been carried out in thermodynamics, from the physical, chemical and biological points of view. For the purpose of this study, those carried out on chemical thermodynamics are reviewed. The main topics which are confused in the chemical thermodynamics are those of chemical energy, heat and temperature, specific heat, work, bond energy, internal energy, enthalpy, entropy, free energy and the direction of the chemical change and spontaneity. They will be discussed in the next sections.

2.4.1 Students' ideas and misunderstandings about chemical energy

Energy is an important topic in chemistry, physics and biology, and its various aspects are central to understanding of science. In order to understand students' difficulties and misunderstandings of energy, numerous studies have been done during the last two decades. Most of the investigations have been undertaken in physics, and little has been done in chemistry or biology. Early studies were mainly concerned about the theoretical aspects of the issue such as Ogborn (1986), Kemp (1984), Solomon (1982), Guidoni (1985), Duit (1985) and Holman (1985), others were intended to implement the results of the former studies into real life such as Cohen and Ben-Zvi (1992), Martins and Cachapuz (1990) and Boohan and Ogborn (1996). These studies resulted in some viable teaching materials and active learning methods being developed. Here, some identified misunderstandings held by students are tabulated.

Table 2.2 Some identified misunderstandings about energy concept

Misunderstandings identified	***Students' age***	***Revealed by***
• Energy is 'being lively'	Secondary	Solomon (1982)
• Energy is an universal fuel	Secondary	Duit (1987)
• Energy is an industrial product which can be obtained from the certain raw materials	Secondary	Duit (1987)
• Heat energy causes water molecules to expand or to break down	17-18 year old (Grade 12)	Griffiths and Preston (1992)
• Confusing potential energy with the gravitational potential	16-19 year old	Archenhold (1979)

Energy is an abstract concept for both students and adults. Previous studies showed that energy was perceived by the students from five different perspectives, these are summarised by Driver *at al* (1994): Energy was seen as:

- *associated only with animate objects*
- *a causal agent stored in certain objects*
- *linked with force and movement*
- *as a fuel*
- *a fluid, an ingredient or a product (p.143)*

Solomon (1982) aimed to identify some of the stages that children might pass through since what they learn at school interacts with their out of school knowledge. She listened to pupils' comments and gave them some open ended questions. Her findings show that energy was perceived as 'being lively'. At this stage, she suggests that energy was not thought to be a measurable quantity, but more of quality. However, Duit (1987) reports that the conception of energy frequently found among pupils was that of a universal fuel. He also reports that pupils perceived energy to be something that is needed to operate machines and to run cars. Pupils felt that energy is an industrial product which can be obtained from certain raw materials. Moreover, pupils think that energy is an item in the sense that it is required to make life more pleasant. For the aim of this study, students' difficulties and misunderstandings of energy in chemistry are discussed.

2.4.1.1 Energy of molecules

Chemistry students have many cognitive learning difficulties about chemical energy, because of the reasons such as cognitive learning difficulties and previous experiences. The main topics which are generally confused are bond energy, potential and kinetic energy, molecular speed, and conservation and the conversion of energy. Griffiths and Preston (1992) interviewed 30 grade 12 students with different abilities and backgrounds in science, and identified five misunderstandings about the energy of molecules. They reported that a considerable proportion of pupils suggested that all water molecules within each phase moved at the same speed. They also asked 'why some water molecules move faster than others and recognised two misunderstandings. The first was that *the speed of the molecules is determined by their size* and the other was that *'some molecules move faster than others because the more space a molecule has to move the faster it will move' (p.621).* The latter two misunderstandings were about applying heat to the water molecules in ice. They revealed that pupils thought that heat causes water molecules to expand and to break down.

2.4.1.2 Conservation and conversion of energy

In order to identify how the principle of conservation of energy is used by the students, Cachapuz and Martins (1987) studied 30 students (fifteen from the 9th grade and fifteen from the 11th grade) who were selected as a volunteers. They firstly taught the principle of conservation of energy and then, students were interviewed individually. The results revealed that the principle of conservation of energy might have been accepted but not properly understood. Grade 11 students were not able to appreciate the conversion of kinetic energy to the potential energy at molecular level and to equate temperature in terms of the average kinetic energy. They stress that:

> *the conservation of energy was introduced in the physics course. It is not because students are able to properly conceptualize the conversion of kinetic energy to potential energy in physics context (where it can be directly observed with the help of mechanical systems) that ideas about energy conversion will be properly used in a chemistry context where the conversion of one form of energy into another essentially lies beyond personal experiences and have to be equated in terms of internal energy (p.66).*

They also reported that more than 90% of the students did not articulate the energy changes with how the reaction took place.

Students' knowledge of potential energy, from a chemical point of view, is considerably naive compared with kinetic energy. Duit (1987) discusses energy as a quasi-material subject and argues that this was because potential and kinetic energy were regarded as essentially different by stating, *'whereas potential energy only exist to speak in our thoughts, kinetic energy is associated more strongly with something observable' (p.142).* The abstract structure of the potential energy relative to the kinetic energy makes it difficult to be grasped by young students and adults as well.

Potential energy was studied from the physics point of view by Archenhold (1979). He aimed to ascertain the degree of understanding of the concept of work and potential by 16-19 year old students and conducted interviews with a sample containing 79 students, all successful in GCE (The General Certificate of Education). He found that a considerable proportion of the students had difficulty in understanding *potential* and 38 out of 79 students confused *gravitational potential* with the *gravitational potential energy.* According to his findings, he suggests that the concept of work done and energy transformations in both uniform and non-uniform fields must be understood before progressing on to study potential.

In order to reduce students' difficulties and misunderstandings of chemical energy, Cohen and Ben-Zvi (1992) developed a new learning package for Israeli high school students. The main topics included in the learning package were exothermic and endothermic reactions, the energy changes, symbols, graphics representation and calculations, energy and chemical bond, standard state and standard heat of formation, compounds and elements, the rolling ion, and energy and ionic compounds. Their learning materials consisted of inquiry questions based on laboratory experiments, teaching aids, structured learning materials and learning games. They offered a variety of activities to optimise student involvement in the learning process and minimise the use of algorithms and working rules. They chose 11th grade students who opted to specialise in chemistry and established three groups of students; a central group of 230 students and two different experimental groups of 334 and 225 students respectively. They found that a variety of learning activities helped students to improve their performance and showed that new concepts should be introduced gradually and supplied by learning materials. They also suggest that high achievers benefit from the inquiry group discussion and that it improves problem solving ability.

2.4.1.3 A summary of students' ideas and misunderstandings about chemical energy

It is clear from the studies reviewed above that energy is an abstract concept for pupils and needs to be made more tangible to allow it to be more understandable. Studies show that students relate the concept of energy to their everyday lives, because the word '*energy*' is commonly. The theoretical explanation of the energy concept is not an effective method of teaching. Some new learning activities and student-centred learning might help students to conceptualize energy. The principle of conservation of energy as stated in the First Law of Thermodynamics is easy to memorise, but the crucial point is the understanding of the idea behind the statement. Therefore, it is important to investigate the understandings of conservation of energy both in secondary school and in university.

2.4.2 Students' ideas and misunderstandings about internal energy

Internal energy is virtually ignored by science educators and chemistry teachers, because 'internal energy' is not covered in secondary school science and only becomes part of the curriculum at university level. Instead of using the term 'internal energy' other terms such as heat, work, potential and kinetic energy terms are studied at the secondary level to explain the first law of the thermodynamics. However, the main body of studies on internal energy are about theoretical aspects of the issue except those of Roon (1992) and Roon *et al* (1994).

Table 2.3 Some identified misunderstandings about internal energy

Misunderstandings observed	***Students' age***	***Revealed by***
• Internal energy only can be changed by heat transfer	Secondary	Erickson and Tiberghien (1985)

The early studies about the concept of internal energy had their origins in Rumford, Black and Joule's works (Kemp 1984). Kemp explains the historical development of the internal energy as:

> *Rumford raised to boiling point the temperature of water surrounding a cannon in which was turned a blunt boring tool driven by horses. In this way, he discredited the belief in conservation of caloric. In showing that it took much longer for ice to reach room temperature than for liquid water originally at the same temperature, Black paved the way to the discovery that a substance gains internal energy on melting. Joule showed, by a series of experiments, that the dis appearance of a given quantity of mechanical energy gave rise to a repeatable increase in temperature for a given mass of water (p.235).*

After their studies, internal energy was explained from the chemical point of view, but there was still little interest in the educational aspects. Some researchers mentioned internal energy when they explained studies on heat and work. One study by Roon *et al* (1994) explores university students' ideas about thermodynamic ideas such as heat, work, internal energy and enthalpy in their introductory course in physical chemistry were explored. They made observations, conducted interviews with the students and asked them to write down their comments on the concepts during the two year course. Each of the 28 lectures was accompanied by a two hour tutorial session, in which students discussed in smaller groups on problem solving and doing exercises. At the end, they concluded that internal energy should be taught by combination of work and heat. They express their ideas by writing:

> *A thermodynamics context is in itself a common context of 'heat' and 'work'. It has no need of 'forms of energy' which can be converted into another. The internal energy of classical thermodynamics has no 'forms'. Internal energy is conserved, but not converted (p.145).*

Similar explanations are given by Erickson and Tiberghien (1985). They stress the most common misunderstanding was that internal energy only can be changed by heat transfer. They express that:

> *It is important to realise that heat transfer is only one way of altering the internal energy of a system. For example a mass of water at temperature T_1 and internal energy E_1 could reach temperature T_2 and internal energy E_2 either by being heated or by being agitated by a paddle wheel. Since there are several pathways for passing from a state with internal energy E_1 to another state with internal energy E_2, it implies that the internal energy state of any system is independent of the type of energy transfer used to achieve that state (p.54).*

Theoretical studies on internal energy were achieved by Waite (1985), Summers (1983) and Se-Yuen Mak and Young (1987). In Waite's study internal energy was defined from the kinetic molecular point of view. Waite concluded that internal energy explains the principal connection between molecular dynamics and thermodynamics. However, Summers's (1983) definition of internal energy was related to the first law of thermodynamics and puts it simply that the internal energy of a substance can be changed by the process of heating or the process of working and that energy is conserved in both situations. Moreover, Se-Yuen

Mak and Young (1987) argued that before talking about internal energy, a system and its state had to be identified, and they then defined the internal energy as:

> *Microscopically speaking, internal energy includes the random kinetic energy and electrical potential energy of all the molecules within the system (p.466).*

In their studies, they generally used the term 'internal energy' to clarify the term 'heat' and 'work'. It appears that there is only a limited amount of research about students' understanding of internal energy.

In conclusion, a shortage of research on students' ideas and misunderstandings about internal energy exists. In the secondary curriculum internal energy is not covered, but instead the concepts of heat and work are studied in greater detail. Clearly further research is needed.

2.4.3 Students' ideas and misunderstandings about work

'*Work*' is a familiar term to everyone but it is also an important scientific concept. Pupils encounter the term throughout their life experiences, but sometimes there are differences between the meaning of the term in school and at home. Therefore, there is the potential to confuse the meaning of the term 'work'. Also, it has different meanings depending upon whether it is being evaluated from a physical or mechanical, chemical or thermodynamical point of view. These might be enough to misrepresent or misunderstand the concept. Some identified misunderstandings are tabulated here and explained in the following section.

Table 2.4 Some identified misunderstandings about work

Misunderstandings observed	*Students' age*	*Revealed by*
• Confusing the concept of work with the potential, force and energy.	16-19 year old	Archenhold (1979)
• Work generally considered as a mechanical concept rather than a thermodynamic concept	University	Roon *et al.* (1994)
• No understanding of 'pV' work	University	Carson and Watson (1999)
• Work is done when bonds are broken or made, or when atoms are ionized	University	Carson and Watson (1999)

Students' ideas about work have been studied from various aspects by science educators. The main body of research on 'work' in thermodynamics is done in association with the term 'heat', as formulated by the first law of thermodynamics. Waite (1985) discusses the kinetic explanation of the thermodynamic process and argues that the laws of thermodynamics developed during the 19th Century were based on experimental observations. Consequently, they did not require an understanding of the detail of molecular mechanics. These macroscopic laws deal with such abstract quantities as heat, work, internal energy and entropy but do not depend on detailed definitions relating these quantities to the microscopic description of matter. Waite (1985) also argues that the basic result was that heat and work, which are often misrepresented and misinterpreted as different *forms of energy*, were best considered as different *mechanisms of energy transfer.* Waite insists that work should be defined as the oriented (nonrandom) transfer of energy, however, Se-Yüen Mak and Young (1987) define work as energy transfer by the action of a macroscopic force or a macroscopic electric current.

Archenhold (1979) studied the understanding of the concepts of work and potential by 16-19 year old students in physics. He presented twenty five pretested tasks and then interviewed the students. He found that about ten percent of the responses would be considered as having a full understanding of concepts associated with work or potential. Nearly seventy percent of the students' responses were either 'no understanding' or 'some knowledge', but little understanding. He also found that many students confused concepts of force, work, energy and potential in GCE A-level physics. Finally, he concluded that the concepts should be frequently used, discussed and tested during a course in order to incorporate the concepts into students' own conceptual scheme.

Roon (1992) and Roon *et al* (1994) report studies on heat and work at tertiary level. Their objective was to design an education strategy which would enable students to develop for themselves a thermodynamic concept of heat and work in a thermodynamic context. They conducted a qualitative research in a freshmen's introductory physical chemistry course in a university over a period of three years. In the first year of the study they concentrated mainly on the students' general problems with the thermodynamic concept of heat and work in a thermodynamic context. In the second and the third year, they concentrated mainly on the way a *transition* from a commonplace concept of work in an ordinary life context to a scientific concept of work. They found that students had difficulty in differentiating 'work' as a thermodynamic concept and perceived 'work' as a mechanical concept. They attribute this to the fact that students related 'work' to 'heat' by means of energy and the mechanical conception of work is coloured by elements from everyday life.

More recently Carson and Watson (1999) state that none of the undergraduates in their study associated work with chemical reactions and concept of 'pV' work was entirely unknown as quoted below:

> ...students cannot envisage a gas being able to do work unless it pushes out a piston, which then does the work against the atmosphere. This is probably a relic of the calculation which converts the relationship: work = F x d to the relationship: work = pΔV (p.50).

In addition, Carson and Watson (1999) reported that some students believed that work was done when bonds were made or broken, or when atoms were ionized. They also found that students attempted to use the definition of work in text books which related work to energy expended in raising weights.

In conclusion, studies on students' ideas and misunderstandings about work mainly focus on physical aspects rather than thermodynamic aspects in secondary school. However, theoretical studies are dominant especially at university level where there is little evidence of studies concerning students' difficulties in thermodynamics. The main difficulty is differentiation of meaning of work used in everyday life and that used in science. In addition, studies show that students perceive the word 'work' as a mechanical concept. It appears that in order to explore university students' knowledge from a thermodynamic point of view, further research is required.

2.4.4 Students' ideas and misunderstandings about heat and temperature

It might be said that one of the best documented areas in thermodynamics is students' ideas and misunderstandings about heat and temperature. The main reason for this attraction might be the fact that heat and temperature are familiar words from daily life. Students' understandings of these concepts is the key to understanding many other scientific concepts. It is also important for scientists to understand students knowledge of these concepts and to develop new curriculums and teaching methods for the science classes. Studies show that even adolescents and scientists have similar misunderstandings about heat, temperature and energy as those of pupils (Lewis and Linn 1994). This could be examined therefore as a crucial point. Some identified misunderstandings are summarised in Table 2.5.

Table 2.5 Some identified misunderstandings about heat and temperature

Misunderstandings observed	***Students' age***	***Revealed by***
• There are two types of heat, cold heat and hot heat	6-13 year old	Erickson (1979, 1981)
• Heat is a material substance like air or steam	6-13 year old	Erickson (1979, 1981)
• Heat is a form of energy	6-13 year old	Erickson (1979, 1981)
• The temperature of an object is related to its size	12 year old	Erickson (1985)
• Heat and temperature are the same	15 year old	Brook et al.(1984-1985)
• Heat is a fluid material	15 year old	Brook et al.(1984-1985)
• Heat transfer start and does not stop at once when the temperature equalized	16-17 year old	Duit and Kesidou (1988)
• Objects at room temperature that feel cold have different temperatures	17-18 year old	Grayson et al. (1995)
• Objects could have a certain quantity of heat in them	17-18 year old	Grayson et al. (1995)
• Objects could get hotter than their surroundings	17-18 year old	Grayson et al. (1995)
• The temperature of water could exceed the boiling point	17-18 year old	Grayson et al. (1995)
• Constant heat means no heat exchange possible	University	Roon (1992)

The studies done on students' understandings of heat and temperature are reviewed. For the purposes of this study, some of the literature concerned with the terminology of heat, the teaching of heat and temperature and some misunderstandings held by students are discussed.

2.4.4.1 Debates on terminology and definition of heat and temperature.

Heat is undoubtedly one of the most difficult concept of the whole secondary science curriculum. Nearly all text books which deal with heat offer different explanations of the term, for example:

- *heat is energy,*
- *heat is form of energy,*
- *heat comes from sun,*
- *heat is internal energy* etc.

These different explanations may cause confusion in understanding the concept. Another source of difficulty in understanding the concept might be the use of words like 'heat capacity' and 'heat flow'. Driver *et al* (1994) report, by referring to Harris, that students' tendency to think of heat as a 'substance' which flows from place to place is not very different from that of Lavoisier. The oldest theory about heat was 'caloric' which was widely accepted during the period before the 1850's (Fuchs, 1987). According to this theory it was assumed that heat (caloric) was conserved. This theory was treated for the cases by Carnot and later by thermodynamicists. Fuchs (1987) explains that:

> *The main problem with the caloric theory of heat can be traced to irreversible processes in which, as Davy's experiment (melting two blocks of ice by rubbing them) had demonstrated, heat must be generated. Today we know heat cannot be caloric if we accept that the usual calorimetric measurements determine amounts of heat (p.162).*

Fuchs (1987) also reports that Rumford's experiments, which were supposed to have demonstrated that heat could not be caloric, did not even prove that caloric was not conserved. In addition, Linn and Songer (1991) used a heat flow model which was similar to the 'caloric' theory embraced by scientists in the 1850's, but differed in that it stressed that heat lacked mass in their heat flow model. Heat was distributed in substances and flowed from warmer to cooler substances until equilibrium was reached. They stress that heat lacked mass and that temperature is a measure of the intensity of heat at a given point. Moreover, Su-Yuen Mak and Young (1987) argued that the caloric theory was probably the major confusion in which there is a conserved substance called heat which is contained inside a body and which flows from a hotter to a cooler body when the two are in contact with each other. They insist that traces of this old and incorrect idea remain in the somewhat misleading terms 'heat capacity' and 'heat gain' which might mislead students into the notion that a body contains some heat, which might be lost or gained.

Another theory about heat is kinetic theory. Linn and Songer (1991) cite a study by referring to Blanc (1971) *et al* which says:

> *According to this theory, the temperature of a substance, whether it is a solid, liquid or gas, is determined by the speed of its moving molecules. As the molecules of a substance collide with each other, their kinetic energy is changed into heat. Friction increases the speed of the molecules. Therefore, the kinetic energy in each molecule is increased. The greater the number of collisions among molecules, the greater increase in the kinetic energy of the molecules. The amount of heat, as a result, greatly increases (p.888).*

Their opinion about this model is that it was too abstract for students and also offered explanations at a level of analysis that did not apply to the results of experiments or to their observations of the natural world. According to them, a model should be chosen that communicates to all students and integrates their observations and experiences. Consequently, they support the caloric theory with some reservations.

Another argument related to the kinetic theory comes from Summers (1983). It was argued that it is not true that the temperature of a substance is proportional to the kinetic energy of its molecules, when the kinetic theory of ideal gases is applied to real substances. Summers (1983) explains this as:

> *it is true to say that the greater the internal energy (which, of course, involves kinetic and potential components) of anyone substance, the higher its temperature will be. But this is an approximation (certainly not a proportionality), and even then is only valid if there is no change of state. In the case of two different substance, it is interesting to note that the same mean energy (total or kinetic) per molecule does not mean that they are at the same temperature (p.674).*

Summers' (1983) argument was that the results for ideal gases should not be extrapolated for real gases, and Summers believes that the kinetic theory of gases was not an ideal vehicle for developing thermodynamic concepts at 'A' level. In addition, Baierlein (1990) discusses the kinetic models in his theoretical paper and concludes that a statement that 'temperature is a measure of the average kinetic energy of the molecules or atoms in a substance' is misleading. Baierlein (1990) insists that the function of temperature is not to tell us about a system's tendency to transfer energy (as heat). According to Bairlein, we must return to the definition that 'temperature is hotness measured on some definite scale'.

With regard to heat, there is a variety of definitions for the concept varying from scientists' to students' viewpoints. Waite (1985) produced a theoretical description and defined heat as a random or non-directed internal energy transfer between different bodies at different temperatures. Waite also accepted the kinetic theory to interpret the temperature changes in any system and concluded that heat and work should not be considered as a forms of energy, but rather as different mechanisms by which internal energy is transferred from system to surroundings.

Roon (1992) also relates the definition of heat and work to system and surroundings. Roon (1992) concludes his argument by stressing that:

> *'heat' and 'work' were words dominating important founding of classical thermodynamics. The thermodynamics quantities, heat and work, are not changes of state quantities. They are process quantities, meaningless in the one important thermodynamics state: the equilibrium state. Perhaps this is one of the main sources of difficulties with these thermodynamic concepts (p.138).*

With regard to terminology, both 'heat' and 'heating' are commonly used. Summers (1983) argues that using 'heat' as a noun should be avoided and 'heating' should be used as a process. Summers defines that *'heating is the name given to the process by which internal energy transfers occur as the result of a temperature difference' (p.671).* However, Su-Yuen Mak and Young (1987) disagree with the Summers' definition by writing:

> *...like to use 'heating' another new term to describe this process. We feel that 'heating' is still not entirely satisfactory. The reason is that the gerund 'heating' in everyday usage can mean (i) the process of heat flows, or (ii) the increase in temperature. In fact, the opposite of heating, namely cooling... usually means the decrease of temperature of a body. The two meaning of 'heating' are not equivalent (p.468).*

Finally, they conclude that the term 'heat' is perfectly adequate so long as attention is drawn to the fact that it is not something stored in a system.

2.4.4.2 Students' understanding of heat and temperature

In this section, students' understanding of heat, heating and temperature are reviewed. Several studies have shown that students have different ideas about heat and temperature to those of scientists. Students can derive these ideas from their daily experiences and even from misrepresented instructions in school.

Children's thinking about heat and temperature is well documented by Erickson (1979, 1980). In the former study Erickson aimed to address two issues which are illustrating one approach to identify a pattern of children's ideas about heat and temperature and indicate that how this knowledge might be used in an instructional setting. Erickson interviewed children ranging in age from 6 to 13. The main point of confusion was that there were two types of heat, 'hot heat' and 'cold heat'. However, children perceived heat as a material substance which reflects the caloric theory of heat. The other interesting belief was that heat (or cold) was a type of substance like air or steam which is capable of flowing into or out of objects.

Erickson (1980) documented children's difficulties in differentiating heat from matter . In this study, Erickson developed an instrument called Conceptual Profile Inventory (CPI) to determine the students' beliefs about heat and temperature. Three different viewpoints were taken into consideration; those are Kinetic Viewpoint, Caloric Viewpoint and Children's Viewpoint which are determined during in depth clinical interviews. The research instrument was administrated in two steps, firstly a demonstration was performed in front of the classroom relating to the topic and then students were asked to make their judgements on a set of six bipolar scales. As a result, Erickson reports that caloric theory was rated higher than other viewpoints and that previously younger students thought heat and cold to be intrinsic qualities of different substances. After the teaching their ideas had changed to think of heat transfer.

Duit and Kesidou (1988) have carried out 14 clinical interviews with German 10th grade students for the purpose of mapping students' conceptions of heat and temperature. Their study showed several students' misunderstandings. Firstly, around 80% of the students had the opinion that when two bodies at a different temperature get in touch they would not reach the same temperature as a result of heat exchange process. They express this situation by writing:

> *Temperature equalization was explained by properties of the bodies involved (e.g. the property to 'be hot' or 'be cold') or the ability to 'give heat' (or cold respectively to other bodies). Usually only the properties of one of the bodies involved were considered (p.191).*

Kesidou and Duit (1993) conducted 34 clinical interviews with grade 10 students. They intended to determine whether some slight enlargements and reorganisations of traditional physics instruction are sufficient or major changes are necessary in order to familiarise students with the basic ideas of the second law. They used open-ended questions to help students to develop their own ideas. The results showed that the majority of the students viewed temperature as a variable that can be measured and/or quantified, while heat was not seen as a measurable or quantifiable concept. The results also showed that only a small number of students, around 21%, used the particle model to explain the concept. In their studies, students did not perceive heat as a form of energy and the responses indicated that they used energy as an intensive quantity. Moreover, the idea of the transformation of kinetic energy to heat was not well developed. They summarised that:

> *students' ideas about whether or not heat energy may be transformed into kinetic energy were also very limited. Heat energy was often considered only as a cause of temperature changes, and motion only as an effect of kinetic energy (p.96).*

Duit and Kesidou report that students were under the impression that 'heat transfer starts and does not stop at once when temperature equalized, and also students' ideas of the process running in a natural direction are mainly based on everyday experiences and not on a scientific basis as taught in school.

Brook *et al* (1984,1985) conducted extensive research to reveal the students' ideas about heat and temperature to find answers to the following four questions.

- *do students differentiate between heat and temperature?*
- *do students appreciate that heat is required to produce a change of state, and that temperature remains constant during a change of state?*
- *do they understand change of state in terms of the particulate model of matter?*
- *how do students conceptualize the conduction of heat through materials?*

They prepared seven different written questions which were given to a group of 300 students aged 15. Their findings revealed that students had several views of heat such as 'heat and temperature are the same', 'heat and cold are opposite and both are fluid materials' and 'some substances are naturally colder than others'. Also the results suggested that the process of heat transfer is better understood by the students when it produces a temperature change than it does not. Students were less able to understand heat transfer and exchange of state in terms of the behaviour of particles. They concluded that the alternative ideas about the change of the state and heat transfer were question-specific. Furthermore, they argued that students do not need to understand the behaviour of particles in order to understand that heat is transferred from an object at a higher temperature to one at a lower temperature.

Grayson *et al.* (1995) conducted a research study with a physics class comprising five year 11 (standards 9) boys in Australia in order to track pupils' development of the concepts of heat and temperature when instructional strategies were employed. The students were given a course material called 'Physics by Inquiry: Heat and Temperature' and then changes in their understanding were monitored. A number of misunderstandings were identified:

- *objects at room temperature that feel different have different temperatures.*
- *objects could have a certain quantity of heat in them.*
- *objects could get hotter than their surroundings.*
- *the temperature of water could exceed at the boiling point.*

They suggest that by using instructional materials and approaches adopted in their study they promoted changes in pupils' understandings of fundamental concepts of heat and temperature.

In order to determine the key factors affecting the understanding of the kinetic theory of heat by children who hold alternative viewpoints, Rogan (1988) conducted a classroom based study in order for the results to be more readily put into practice by science teachers. 145 students whose mean age was 14.61 years participated to the study. His study was based on three themes:

- *designing two different instructional sequences*
- *developing different types of learning environments*
- *dividing the students into low and high reasoners*

One of those learning environments was designated cooperative group in which students work together in groups of about four and the other learning environment was called individual. In the research two instruments which were formerly designed and used by Lawson and Erickson were used. The instruments were used as a pretest, a post-test and a retention test. According to results, he suggested that the articulation of different viewpoints in no way hinders the acquisition of the desired conceptual framework.

In order to develop the teaching quality of elementary thermodynamics Linn and Songer (1991) designed a thermodynamics curriculum by using earlier test results.

All curricula based on the teaching of a 'pragmatic model' of the thermal phenomena based on the idea of heat flow similar to the caloric theory. Their curriculum called CLP (Computer as Lab Partner) devoted 13 weeks to experiments and 20 weeks to instruction and took place in the physical science class during one semester. In order to assess students understanding of thermodynamics, they used the HTA (Heat and Temperature Assessment) tests. They suggested that the kinetic theory model was ignored by the students and that they did not integrate the results of their experiments with the theory. They argued that:

> *The kinetic theory model, with the emphasis on molecular motion, requires analysis of the experimental results in terms of kinetic theory because many difficult assumptions were required to integrate their understanding of experiments with kinetic theory. Students must imagine a hidden mechanisms and our investigations suggest that this is too abstract and difficult (p.904).*

In a recent study, Lewis and Linn (1994) identified concepts of heat energy and temperature held by adolescents, adults and scientists. They conducted clinical interviews with 37 students from the 8th grade (ages 12-14 years old), 9 adults, and 8 chemists and physicists to reveal their predictions and explanations of the real world phenomena. While adolescents and adults gave remarkably similar responses to the interview questions, scientists gave meaningful explanations to the real-world phenomena. Some scientists also used intuitive conceptions in responding to the interview questions.

Erickson (1985) reviewed related studies on heat and temperature. It was reported that most pupils were aware of the transfer of heat from objects at a higher temperature to those at a lower temperature and that they also had a number of plausible explanations for the process. Erickson (1985) also reported that pupils believed that the temperature of an object is related to its size. For example, more than half of the 12 year old children thought that a large ice cube would have colder temperature than a small one.

In another review, Tiberghien (1985) revealed students ideas of the kinetic molecular theory many of these students had received formal instruction in the subject. Tiberghien noted that children had an idea that heat is hot, but temperature can be cold or hot and also that some of them thought that there is no difference between heat and temperature. In addition, children thought that temperature will change during melting or boiling.

Two studies were compiled with the aim of understanding the university students' ideas about heat and work by Roon (1992) and Roon *et al* (1994). The studies were completed in three years as described in section 2.4.3. Roon (1992) reported that students thought that 'constant heat' meant 'no heat exchange possible' and that heat was perceived as a 'state quantity', 'something in a body' instead of a process quantity. In a subsequent study, Roon *et al* (1994) reached the conclusion that students' conception of heat was what they term an 'energetic heat concept', because the students perceived heat as an energy.

2.4.4.3 A summary of students' ideas and misunderstandings about heat and temperature

It has been shown that there are many misunderstandings held by students about heat and temperature. They are undoubtedly amongst the most difficult ideas in the secondary science curriculum and also at university. This difficulty may arise from the terminology used differently, the same word used in everyday life and school curriculum may have different meanings. Also heat and temperature are sometimes used interchangeably by mistake. Schuster (1983) suggests that labels or terminology can be useful in organising ideas in a field, but they can inhibit creative thinking or alternative approaches if they are overly simplistic or inappropriate. Another possible source of these misunderstandings could be the definitions of the terms in text books. Some misunderstandings may also come from the teachers and textbook writers who do not agree on the definition of the terms. Studies show that it is possible to manage changing these misunderstandings by using computers in school courses, giving importance to the laboratory experiments and making clear definitions for the terms.

Although many studies have been carried out on the topic, there are still unexplored areas surrounding the meaning and usage of the terms perceived by university students. The understanding of the concepts of heat and temperature could be different for them. The model (eg. the kinetic molecular theory or caloric theory) accepted and used by university students to explain the concepts is also an important point. It is worth investigating further to reveal the university students' understanding of the heat and work relationship and differences from the kinetic molecular theory and caloric model point of views. Moreover it is worth to look at students' explanations about heat and heat capacities.

2.4.5 Students' ideas and misunderstandings about enthalpy and spontaneity

Enthalpy is one of the fundamental thermodynamic ideas in chemistry. Students learn this subject generally in upper secondary school or at higher level. In secondary school students are mainly taught the concepts 'heat' and 'chemical energy' instead of enthalpy. Enthalpy is defined as the heat exchanged with the surroundings in the course of a reaction which occurs at constant pressure (Maple 1997, p.145). Students' ideas and misunderstandings about enthalpy have received relatively little attention from science educators and researchers, however Carson and Watson (1999) studied students' understandings of enthalpy change and also the energy changes in a chemical reaction and bond energies have been studied by Boo (1998). Some of the misunderstandings which were revealed are tabulated below.

Table 2.6 Some identified misunderstandings about enthalpy and spontaneity

Misunderstandings identified	*Students' age*	*Revealed by*
• Endothermic reactions cannot be spontaneous.	17 years old University	Johnstone *et al* (1977) Thomas (1997)
• Viewing enthalpy as a 'form of energy'	University	Carson and Watson (1999)
• Incomplete definition of enthalpy change	University	Carson and Watson (1999)
• No heat occurs under isothermal conditions	University	Thomas (1997)
• Bond breaking release energy, conversely bond making requires energy.	15 years old 16-18 years old	Boo (1998) Barker and Millar (1996)
• A chemical reaction is spontaneous, if we do not need to interfere.	University University University	Ribeiro *et al* (1990) Anderson *et al* (1999) Selepe and Bradley (1997)
• A chemical reaction is spontaneous, if it is observable.	University	Ribeiro *et al* (1990)
• Spontaneous reactions occur rapidly	University	Selepe and Bradley (1997)
• No activation energy required in spontaneous reactions	University	Selepe and Bradley (1997)
• Spontaneous reactions occur when heat evolves from the system to the surroundings	University	Selepe and Bradley (1997)

The First Law of the Thermodynamics, which states that the energy of an isolated system is constant, is taught to high school students in order to apply this in calculations of enthalpy changes in the chemical reactions (Barker 1995). It is a basic idea that energy is released when bonds form and energy is required to break the bonds. Studies show, however, that students' understanding is often the opposite of this (Boo 1998).

High school students' ideas about thermodynamic concepts such as enthalpy, entropy and free energy were addressed by Johnstone *et al* (1977). In order to reveal the conceptual difficulties experienced by students, they wrote a *thermodynamics approach* test which was given to 98 pupils from ten different schools. The results showed that approximately one pupil in six had the misunderstanding that endothermic reactions can not be spontaneous. They attributed this to the universal rule that situations tend spontaneously to a lower energy position. They also noted that this misunderstanding was not new and historically there was a belief held by the famous chemists, Berthelot and Thomsen in 1878, that reactions have to be exothermic to be spontaneous. They suggested that this kind of misunderstandings could be overcome by teaching in a small group of students. A large lecture class is not the best medium for the presentation of thermodynamic concepts. Thomas (1997) reported the same misunderstanding in 75% of the college students who took the physical chemistry course. He also found that 60% of the students thought that no heat transfer occurs under isothermal conditions.

In a more recent study Carson and Watson (1999) studied first year chemistry undergraduates' understandings of 'enthalpy change' and found that students viewed enthalpy as a 'form of energy'. In addition, none of their sample were able to associate work with chemical reactions and the concept of 'pV work' was unknown. Moreover, it was found that 9 out of 16 students were not able to give precise definition for enthalpy change. Their definitions were restricted to a specific type of reactions such as neutralisation. In the same study students also were asked about common thermodynamic mathematical expressions but found that many of the students did no more than recognise the names of the symbols.

Ross (1993) notes that many students thought that energy is released when chemical bonds break in contrary to the chemists' view. Ross suggests that these misunderstandings arise due to the association between fuels and energy developed by students and that this is a barrier to learning the concepts. He argues that misuse of terms in everyday life causes students to develop misunderstandings and therefore words should be chosen carefully in teaching. Additionally, students should be given more time to reinterpret, use and apply the new ideas in their science lessons. Barker (1995) studied A-level students' ideas about thermodynamics and found that only 1 in 5 beginning A-level students thought that bond breaking released energy, and conversely bond making required energy. This was the similar to the findings of Ross (1993). She attributes this to the fact that fuels are taught to be 'energy stores'.

Spontaneity and reaction are the other concepts in chemistry that are generally confused with their everyday meanings. Ribeiro *et al* (1990) define these two terms:

> ***A chemical reaction is a material process in which a new substance is formed. A spontaneous reaction is one which has a natural tendency to occur; one which has products with lower free energy than the reactants (p.392).***

In order to find out how fourth-year undergraduates in chemistry interpret the chemical phenomena using the words *reaction* and *spontaneous* Ribeiro *et al* (1990) conducted a clinical interview study with 14 students. The students were shown four experiments related to the topic and then they were asked about the phenomena. The results revealed that the majority of the students used the everyday notion of the word 'spontaneous', thus the word 'spontaneity' was related to observable features such that *a chemical reaction is spontaneous if it is observable*. The findings also revealed another misunderstanding, that *a chemical reaction is spontaneous if we do not need to interfere*. According to them, the main source of these misunderstandings is everyday use of the words. It was stressed that science teachers must pay careful attention to everyday, out-of-class ideas associated with the concepts. Another suggestion was that students should be helped to see clearly the contextual differentiation of their knowledge. The final comment was that students should be given closer guidance when they are trying to apply theoretical knowledge to practical situations. It is argued that conventional lectures and laboratory classes may not be the best vehicles to overcome these misunderstandings.

In another study Selepe and Bradley (1997) investigated 56 final year college student-teachers' ideas and areas of conceptual difficulties in thermodynamics.

They used questionnaires and interviews. Their research revealed similar misunderstandings as with Ribeiro *et al* (1990) but also some new ones such as that spontaneous reactions occur rapidly, have no activation energy, and spontaneous reactions occur when heat evolves from the system to the surroundings. They also found that the sign of the change in enthalpy was used as a determinant for spontaneity. They argued that everyday usage of the word 'spontaneity' which means 'immediate action or rapidity' causes misunderstandings in students.

In conclusion, the studies on students' ideas about enthalpy and spontaneity are inadequate since no systematic study has been carried out to determine the relationship with the other thermodynamic concepts. Advanced studies on university students' ideas about the relationship between the reaction enthalpy, reaction rate, spontaneity and activation energy and enthalpy change would yield useful results.

2.4.6 Students' ideas and misunderstandings about entropy and spontaneity

Entropy is a fundamental concept in chemical thermodynamics that helps to explain the natural tendency of matter and energy in the universe to become less ordered (Tomanek 1994). This is an explanation of the Second Law of Thermodynamics which states that entropy increases when a chemical reaction occurs spontaneously. In general, students seem to have less problem with the second law, because it does not run against students' everyday experiments and it is in accordance with the requirements of the school science curricula. Students generally interpret the concept of entropy as a measure of disorder according to

Johnstone *et al* (1977). Although the recent research by Selepe and Bradley (1997) and Ribeiro (1992) support Johnstone *et al* findings, there are evidences that students misunderstood the second law. The misunderstandings identified are tabulated and discussed below.

Table 2.7 Some identified misunderstandings about entropy

Misunderstandings observed	***Students' age***	***Revealed by***
• When the entropy is increased, the temperature is also increased.	17 years old	Johnstone et al (1977)
• When a released rubber band contracts entropy is decreased.	17 years old	Johnstone et al (1977)
• According to the Second Law, the entropy of *the system* must increase for a spontaneous change	University	Thomas (1997)
• Entropy equals the disorder of the system	University	Selepe and Bradley (1997)
• Entropy is the cause for the disorder in the system	University	Selepe and Bradley (1997)
• CO_2 has bigger entropy than C_3H_8 at the same temperature	University	Selepe and Bradley (1997)
• Entropy shows that work has been done on the system	University	Selepe and Bradley (1997)
• A micro state is a little state, it is not related with entropy	University	Ribeiro (1992)
• Entropy of the universe does not change or decrease	University	Ribeiro (1992)
• A system always goes to maximum entropy	University	Ribeiro (1992)
• The change of entropy of a reaction is always positive	University	Ribeiro (1992)
• In an isolated system the change of entropy is greater or equal to zero	University	Ribeiro (1992)

Johnstone et al (1977) report that there was some tendency to confuse entropy with kinetic energy. They explored this confusion from an easy rubber band experiment in which a rubber band at room temperature has more entropy value than when it is released. Their study showed that nearly half of the students considered that the entropy value of released rubber band was more than its initial state ,and also that its temperature must increase when it contracts in contrast to the scientific view. They concluded that:

> *Increase in entropy, therefore, seems to equate with increase in temperature, perhaps through some misconceptual notion of disorder (p.250).*

Similar kind of results were also identified by Selepe and Bradley (1997). They concluded that there seemed to be a strong relationship between entropy and kinetic energy of the particles.

Another misunderstanding explored by them resulted from a misinterpretation of the term 'disorder' as 'chaos'. Johnstone *et al* thought that the source of this misunderstanding was the point taught where a haphazard array of tumbled building bricks was accorded 'greater entropy' than the original ordered array. Ribeiro (1992) also found that the students' understanding of the word 'disorder' is different from its scientific meaning. Students used disorder in the sense of chaos or randomness. It was also reported that the majority of the students considered that disorder was larger when the energy increased (p. 27). Moreover, Selepe and Bradley (1997) found that students perceived entropy and disorder as equal or that entropy was the cause for the disorder in the system. They also found that students perceived that entropy shows that work has been done on the system.

Finally, they asked students to compare the entropy values of carbon dioxide and propane at the same temperature. The results showed that seven out of ten students thought that carbon dioxide had a bigger entropy than propane at the same temperature.

Ribeiro (1992) interviewed 14 Portuguese undergraduates in chemistry in their final year. It was reported that although the majority of the students remembered the term microstate, only a few of them ware able to explain it in terms of the possible arrangements of the particles. It was also found that microstate was perceived as a little state and not related with entropy. In the same study it was also revealed that students have such misunderstandings as that entropy of the universe does not change, a system always goes to maximum entropy, the change of entropy of a reaction is always positive and finally, in an isolated system, the change of entropy is greater than or equal to zero. Ribeiro (1992) suggests that university teachers should determine students' existing knowledge, lecturers should be careful in the language they use, scientific ideas must be shown to be useful to explain real phenomena and students should be helped to see clearly the contextual differentiation of their knowledge more clearly.

Duit and Kesidou (1988) interviewed 14 students to discover 10th grade (about 16 years old) high school students' understanding of the Second Law and irreversibility. They discovered that most of the students had the correct idea that heat flows from a hot body to a cold body and that temperature differences tend to equalize. Contrary to this result, there was a considerably number of students who thought that a certain temperature difference might arise after the temperature equalisation. Their concluding remark was that students' ideas about the natural processes were mainly based on everyday experiences rather than scientific ones taught in school. In a subsequent study Kesidou and Duit (1993) suggested two ways to overcome this misunderstanding. Firstly, the experiments should be carried out by the students and secondly a framework should be provided that conceptualises the thermal interaction as an exchange of heat that runs spontaneously as long as there is a temperature difference.

Tomanek (1994) reports a classroom based study conducted in a secondary Environmental Science class which explored the idea of entropy in the study of basic ecology. The data was collected during 9 weeks school time by making audio recordings of all class sessions and by interviewing students. The study revealed many invise ideas developed by secondary students. Some of those ideas are:

- *Entropy governs matter and energy in such a way that both became less ordered and less useful for human purposes.*
- *Increasing the rate of entropy decreases the amount of 'useful' matter and energy.*
- *Maintaining living systems increases the entropy.*
- *Highly consumptive life styles accelerate the entropy.*
- *Reducing the amounts of waste matter and waste energy that enter the environment reduce the entropy.*
- *Entropy contributes to the process of ecological succession. (p.79).*

Tomanek's study shows that students could develop scientifically acceptable ideas if they are taught concisely. Tomanek's students learned entropy as a physical law of nature rather than an idea that matter becomes more mixed up. It would be useful to develop tasks at the beginning of the course leading students to discuss, and confront alternative ways of thinking about entropy.

As a concluding remark, studies on students' understanding of the concept of entropy are restricted. Although there are some studies which reflect the theoretical aspects and students' understandings, there is no systematic extensive research. Students' difficulties with entropy need further study as do the other thermodynamic concepts. High school and university students' understanding of the relationships between entropy changes and temperature, entropy and spontaneity, entropy changes in the case of solid and liquid matter would benefit from further research.

2.4.7 Students' ideas and misunderstandings about free energy and spontaneity

Free energy is generally thought of as a subtle idea. This idea is taught in high school and further level as well as other thermodynamic concepts such as enthalpy and entropy. In fact, the term 'free energy' used by scientists is not so different from the term 'energy' used by pupils (Ross 1988). Free energy was called by different names such as 'exergy' by Ogborn (1986), 'fuel value' or 'available energy' by Ross (1986). In his theoretical based articles, Ogborn (1988) defined the free energy as 'go' of things or sometimes 'capacity to do work'. He wrote that:

> *Free energy is generally costly, important not to waste, easily slips through our fingers and gets lost, and is what 'makes things happen'. Any process which happens will use some free energy up. A process which (overall) increases free energy cannot happen. To make it happen, more free energy must be lost somehow than is gained (p.83).*

His idea was that if something makes things happen it has free energy. For example, '*a furnace has free energy because it makes things happen*'. Moreover, Ross (1988) suggests different names for three different situations; the term 'energy' to the man in the street, 'fuel value' or 'available energy' for use in school and the term 'free energy' for use by scientists. He prefers the term 'fuels', for the students because; *'fuels have available or free energy which can be used to drive systems. ... uranium 'fuels' nuclear power plants,... petrol 'fuels' our cars' (p.445).*

A number of misunderstandings identified by some other researchers are given in Table 2.8.

Table 2.8 Some identified misunderstandings about Gibbs energy and spontaneity

Misunderstandings observed	***Students' age***	***Revealed by***
• If a reaction has large Gibbs energy change it will occur rapidly.	17 years old	Johnstone *et al* (1977)
• Possibly, the net rate of reaction in a system tends to zero as equilibrium is approached.	17 years old	Johnstone *et al* (1977)
• High negative value of ΔH and positive value of $T\Delta S$, make the right-hand side of the equation negative; hence, ΔG is negative and the reaction is spontaneous.	College (BScEd)	Banerjee (1995)
• Gibbs energy would increase or decrease linearly to make the reaction spontaneous either in the direction $A \rightarrow B$ or $B \rightarrow A$, depending on whether A (reactant) or B(product) had more Gibbs energy to start with.	College (BscEd)	Banerjee (1995)
• ΔG is the thermal energy transferred into or out of the system	University	Thomas and Schwentz (1998)
• Confusing ΔG (the change in Gibbs energy between two states) with Gibbs energy itself so that Gibbs energy of the system either asymptotically approaches zero or goes to zero at equilibrium	University	Thomas (1997)
• ΔG^{θ} is the same as ΔG except that ΔG^{θ} is measured at standard temperature (298K) and standard pressure (1 bar), whereas, ΔG is measured at any particular temperature and pressure	University	Thomas (1997)
• Free energy is the energy taken out or lost by the system during a reaction	University	Selepe and Bradley (1997)
• Free energy is the energy that has not been used to make the reaction occur	University	Selepe and Bradley (1997)
• Free energy is the internal energy that makes substance react	University	Selepe and Bradley (1997)

It was observed that A-level students had some serious misunderstandings about the Gibbs energy. Johnstone *et al* (1977) identified that nearly a quarter of the subjects thought that if a reaction had a large Gibbs energy change it would occur rapidly. They also thought that there was a misunderstanding, which was not tested, that the net rate of the reaction in a system tends to zero as equilibrium is approached. They suggested that this was because of the fact that the value of

ΔG tends to zero. It was also suggested that misunderstandings of thermodynamic ideas arose among high school students would be because of the fact that they are not mature enough to appreciate the conceptual subtleties of the subject. The remedies for these kinds of misunderstandings might include the suggestions that students should avoid using too much mathematics during learning the thermodynamic ideas, and also helping the students to make the correct connections with their existing knowledge.

Banerjee (1995) studied 60 third semester college students' (BScEd) ideas of chemical equilibrium and thermodynamics. An achievement test on thermodynamics and equilibrium was developed and given after 12 weeks to assess the conceptual understanding and problem-solving abilities of the students. Many widespread misunderstandings were revealed. One of those misunderstandings was that in an equilibrium reaction, a high negative value of ΔH and positive value of $T\Delta S$, make the right-hand side of the reaction negative. Hence, ΔG is negative and the reaction is spontaneous. This misunderstanding arose from the misinterpretation of the fundamental equation of thermodynamics, $\Delta G = \Delta H - T\Delta S$. Banerjee argues that students used the logic correctly but the interpretation was wrong. It is a common misinterpretation which takes place in most school textbooks. Banerjee explains that:

> *The tendency to lower Gibbs energy is solely a tendency toward greater overall entropy. Systems change spontaneously solely because that increases the entropy of universe, not because they tend to lower energy....The equation* $\Delta G = \Delta H - T\Delta S$ *gives the impression that systems favour lower energy, but this is misleading.* ΔS *is entropy of the system and,* $-\Delta H/T$ *is the entropy change of the surroundings. Total entropy tends toward maximum for spontaneous reaction (p.880-881)*

Banerjee argues that the driving force was entropy rather than lower energy for the spontaneous processes.

The second misunderstanding was identified from the question: '*Draw a graph of Gibbs energy versus extent of reaction of A → B*'. Students thought that Gibbs energy would increase or decrease linearly to make the reaction spontaneous either in the direction A → B or B → A depending on whether A(reactant) or B(product) initially had more Gibbs energy. Banerjee comments that students were not able to conceptualise that Gibbs energy has the lowest value at the equilibrium position. Banerjee also argues that these kinds of misunderstandings should not be thought of being specific to this sample. They are widespread among students and even teachers.

More recently Thomas (1997) revealed students' misunderstandings in thermodynamic concepts in physical chemistry. He reported that students considered that ΔG^{θ} is the same as ΔG except that ΔG^{θ} is measured at a standard temperature (298K) and standard pressure (1 bar), whereas, ΔG is measured at any particular temperature and pressure. He also reported that students confused ΔG (the change in Gibbs energy between two states) with Gibbs energy itself so that Gibbs energy of the system either asymptotically approaches zero or goes to zero at equilibrium. In another study, Thomas and Schwentz (1998) reported that students perceived Gibbs energy as the thermal energy transferred into or out of the system.

Finally, Selepe and Bradley (1997) reported that students understanding of free energy was rather superficial. Six out of ten students said that free energy is the energy taken out or lost by the system during a reaction. In addition, two out of ten argued that free energy is the energy that has not been used to make the reaction to occur and free energy is the internal energy that makes substances react.

The discussion shows that Gibbs energy is found to be a difficult idea to be grasped by high school students and undergraduates alike. In many cases students' understanding of the basic ideas is limited, distorted or wrong. The difficulties arise from misinterpretation of mathematical equations in thermodynamics and not adequately integrating the new knowledge with students' existing knowledge. Students' explanations are mostly based on the macrophysical world, their thinking on the microphysical world is limited. The everyday meanings of the scientific terms dominate their interpretations. Lecturers should check that students have acquired the correct scientific meanings of the concepts and apply them in both everyday and theoretical situations.

2.5 Conclusions

The literature review summarises the studies of students' understandings of the basic thermodynamic ideas. The review also highlights the strategies which were employed to overcome the students' misunderstandings. The literature review suggests that a number of research studies had been done at secondary level about basic chemical ideas in thermodynamics, but there is a lack of research at tertiary level. Much of the research focussed on ideas such as energy, heat, temperature and the particulate nature of matter, for example Erickson (1979. 1981), Brook *et al* (1984, 1985), Duit and Kesidou (1988), Grayson *et al* (1995). Only limited research has been carried out on thermodynamics ideas such as internal energy, enthalpy, entropy, Gibbs energy, for example Johnstone *et al* (1977), Barker (1995), Boo (1998) at secondary level. The majority of the research done at tertiary level represents small samples and no systematic research has been done on undergraduates' understandings of basic ideas. As a result, these findings show that there is a shortage of research at tertiary level about students' understandings of basic chemical ideas in thermodynamics. Further research is required to understand students' strengths and weaknesses in order to create a better teaching and learning environment.

Chapter 3

Chapter 3

Methodology:

Planning and Designing of the Research Study

The purpose of this research is to identify and classify chemistry undergraduates' misunderstandings of thermodynamic ideas in physical chemistry such as internal energy, enthalpy, entropy and Gibbs energy, together with the sources of these misunderstandings. This chapter describes how the research was planned and designed to meet the aims of the study. The main source of data is students' responses to diagnostic questions with the written data being supplemented by interviews performed with selected students. This chapter outlines the research procedures used in the study including:

- details of the formulation of the research study
- the aspects of the physical chemistry course content in the participant universities
- how the research instrument was planned and developed including the content of the questions and the pilot study results
- the data collection issues
- how the analysis of the data collected has been done.

It also describes how the interviews were carried out and the results were analysed. The strengths and weaknesses of the data collection instruments are discussed and possible other data collection tools are addressed. The constraints of the data collection are also addressed including the validity and reliability of the data collection tools and data analysis.

The key events of the research study are summarised in Table 3.1.

Table 3.1. Time line for the research study showing dates of key events.

Year	*Month*	*Event*
1997	December-April 1998	Summary of literature
1998	March	Development of questionnaire and discussion with the colleagues in the department
		Writing invitation letters to the universities to participate in the research study
	May	Piloting the trial questions and conducting interviews in Turkey
	June-September	Analysis of the pilot study results and developing of coding schemes, and preparing the final version of the questionnaire.
	October	First administration of the questionnaire as pre-test and conducting interviews in Turkey
	November-May 1999	A first attempt to develop coding scheme and early analysis of the pre-test responses, and transcribing the pre-interview tape cassettes.
1999	May	Second administration of the questionnaire as post-test and conducting post-interviews in Turkey
	June-October	Development of the coding scheme
	October-onwards	Analysis of the post-test responses
		Transcription of the post-interview tape cassettes and analysis of the interview results.
		Writing up the thesis
2001	June	Submitting the thesis

3.1 Formulation of the Research Study

In this section the factors influencing selection of the research methods are discussed. The strengths and the weaknesses of the methods employed are explained along with reasons why other methods were not chosen. The limitations of the study are also discussed.

3.1.1 Research methods

In their review of twenty years of research into students' misunderstandings in science Wandersee *et al* (1994) reported that researchers commonly used interviews, questionnaires with multiple choice and open ended questions, classification and association tasks, essay writing, concept mapping and problem solving activities. It has been also reported that the interview technique and questionnaires were the most commonly used techniques (Wandersee *et al* 1994). Each of these is discussed in more detail below.

Questionnaires

> *There is no 'golden formula' which, if slavishly adhered to, will ensure success and send off all potential criticism. Almost, inevitably, the researcher will need to apply direction, to make trade-offs and exercise judgement when producing and implementing a questionnaire (Denscombe 1998, p.87)*

Questionnaire techniques are widely used in educational research studies. Diagnostic questions were found to have successfully identified students' misunderstandings of microscopic descriptions related to thermodynamic ideas such as heat, internal energy, system and surroundings and relationship between temperature and heat, as well as between temperature and kinetic energy (Rollnick and Mahooana 1996). Various written questions have been used in an attempt to reveal the student's underlying assumptions. For example, multiple choice questions are often used since they are easy to administer and mark (Tamir 1971). Treagust (1988) has developed a series of two tier diagnostic questions which begin with an open ended part and end with multiple choice questions. '*The first tier of each item consists of a content having two, three, or four choices: the second part of each item contains four possible reasons for the answer given in the first tier*' (Peterson and Treagust 1989, p. 303). Open ended questions were also considered one of the most powerful research tools to reveal students' underlying thoughts. Open ended questions are '*those that leave the* *respondent to decide the wording of the answer, the length of the answer and the kind of matters to be raised in the answer. The questions tend to be short and the answers tend to be long*' (Denscombe 1998, p.101). The main advantage of the open ended question is that the information gathered is more likely to reflect the full extent and complexity of the views held by the students (Denscombe 1998). However, there are also disadvantages. For example, they demand more effort and therefore they may reduce the willingness of the respondent to answer the questions, or take part in the research. In addition, they produce 'raw' data which requires time-consuming analysis. However, open-ended questions were successfully produced and used in educational research (Barker 1995) and it has been reported that 7% of research has been carried out on students' misunderstandings using open ended tests (Wandersee *et al* 1994).

Interviews

An interview can be defined as '*a conversation between interviewer and respondent with the purpose of eliciting certain information from the respondent*' (Bell 1993, p.91). Interviews are thought to be potentially the most powerful and direct method of assessing students' understanding (Abdullah and Scaife 1997, Schuster 1983). In science education research, two types of interviews are commonly used; these are *Interviews about Instances and Events* and *Interviews about Concepts* (White and Gunstone 1992). *Interviews about an instance or an event* are defined as '*a conversation that an expert has with one student, focussed by initial questions about situations represented in a series of line diagrams, to check the students' ability to recognise the presence of a concept or the students' interpretation of a natural phenomenon or social occurrence* (ibid, p.65). *The* *interviews about a concept* are defined by the same researchers as '*a conversation designed to bring out the knowledge that a person has about the concept*' (ibid, p.82). Although interviews are possibly the most powerful way of exploring students' understanding of a particular idea, there are problems with their application. One of the disadvantages of interviews is that they are too time consuming and therefore it is not appropriate to collect data from a large sample. Moreover, it is a highly subjective technique and there is always a danger of bias (Bell 1993). Interviews can yield too much raw data which is time consuming and difficult to analyse.

There are other methods which have been employed to identify misunderstandings. For example Novak (1990) employed concept mapping, Alvarez and Risko (1987) and Novak (1984) made use of Vee diagrams (*a structured, visual means of relating the methodological aspects of an activity, such as a science experiment, to the underlying conceptual aspects*), and Champagne *et al* (1985) used POE (prediction, observation, and explanation). However, in this study, open ended questions in a questionnaire were chosen as a main data collection tool in conjunction with interviews. This was done for a number of reasons. Firstly, questionnaires are easy to administer and data collection is less time consuming. Since there were time restrictions in collecting data from overseas, the questionnaire technique was appropriate. Open ended questions were chosen instead of multiple choice questions because the pilot study showed that open ended questions generated a wider range of responses compared to multiple choice questions. This will be further explained in Section 3.4.3. Secondly, it is evident from the literature that the questionnaire technique has been widely used for the purpose of research and its effectiveness and success has been proven where it has been used correctly.

The interview technique was included because its' strength in exploring students' underlying concepts. It was reported that interviews are powerful technique in exploring students' misunderstandings (Wandersee *et al* 1994). Although they are very powerful in diagnosing misunderstandings, the interview technique was not chosen as the sole data collection tool for a number of reasons. The interview and questionnaire techniques were used together to improve the credibility of the findings and interpretations. Lincoln and Guba (1985) mentioned the importance of triangulation in social research by stating that:

> *Triangulation of data is crucially important in naturalistic studies. As the study unfolds and particular pieces of information come to light, steps should be taken to validate each against at least one another source (for example, a second interview) and/or a second method (for example, an observation in addition to an interview). No single item of information (unless coming from an elite and unimpeachable source) should ever be given serious consideration unless it can be triangulated* (p.283).

They suggested that there are four different modes of triangulation. These are the use of multiple and different sources, methods, investigators and theories. '*The concept of triangulation by different methods thus can imply either different data collection methods (interviews, questionnaire, observation, testing)* or *different designs'* (ibid, p.306). In this study, a combination of two different data collection methods has been employed to apply triangulation. Another reason why the interview technique was not chosen as the sole data collection technique was that it is time consuming. Since, there was limited time available for data collection from overseas, it was impractical to collect all data from interviews. Therefore only a limited number of interviews were conducted to supplement the questionnaire data.

In addition to the questionnaire and interviews carried out to determine students' misunderstandings of four main physical chemical ideas and related ideas, another questionnaire sheet was prepared in order to explore what students thought about the sources of the misunderstandings and possible solutions. In order to do this, two open ended questions were posed:

> ***Question 1:*** *What do you think makes it hard for you to understand chemical ideas in physical chemistry? Please discuss with your friends in groups and write them down.*
>
> ***Question 2:*** *What do you think could be done to help you understand these ideas better? Please discuss with your friends in groups and write them down.*

The questionnaire sheet can be seen in Appendix 9.

3.2 Content of Physical Chemistry Courses and the Decision on Which Aspects to Investigate

The decision on which data collection methods were to be used proceeds the question '*which aspects of the physical chemistry should be investigated*'. Physical chemistry is a huge subject and covers various topics such as thermodynamics, kinetics, electrochemistry, spectroscopy, quantum chemistry, surface chemistry. It is classified by Atkins (1997) into three main streams.

> *Physical chemistry establishes and develops the principles that are used to explain and interpret the observations made in the other branches of chemistry. Physical chemistry is characterised by three main approaches: the discussion of bulk properties in terms of thermodynamics, the use of spectroscopy to explore the behaviour of individual atoms and molecules, and the analysis of the rates and mechanisms of chemical change (p. 1).*

In this definition Atkins makes three main divisions; '*equilibrium*', '*structure*', and '*change*'. '*Equilibrium*' is mainly dominated by chemical thermodynamics; '*structure*' is dominated by quantum mechanics and spectroscopy, and '*change*' is the main domain of chemical reaction. The topics covered in physical chemistry are summarised in Table 3.2 .

Table 3.2 Main subject structure of physical chemistry

Physical Chemistry		
Equilibrium	**Structure**	**Change**
Gases and kinetic molecular theory First law Second law Third law Physical transformation of pure substance The properties of mixtures Phase diagrams Chemical equilibrium Electrochemistry	Quantum theory Atomic structure and atomic spectrum Molecular structure Spectroscopy	Chemical kinetics Molecular reaction dynamics The properties of surfaces Dynamics electrochemistry

3.2.1 Physical chemistry course content in the participant universities

Physical chemistry is taught in the third year in two semesters in the participant universities. Although the laboratory course is compatible with the theoretical course there are a few exceptions. The laboratory course is given simultaneously with theoretical course in one of the universities but it is given at the following year in the other university.

The course content is mainly covered with '*equilibrium*' with the exception of *electrochemistry* and the *phase diagrams* which include a small element of '*change*' as defined in section 3.2. The '*structure*' section alone is not taught except for spectroscopy, which is included in the laboratory course content. Since electrochemistry is taught as a separate subject it is not included in the course content. Surface chemistry and phase diagrams are represented with one or two experiments in the laboratory courses rather than presented in the theoretical course. The chemical kinetics from the '*change*' section is presented towards the end of the second semester over a two month period.

In summary, the course content is mainly dominated by two areas; '*chemical thermodynamics*' and '*chemical kinetics*'. Therefore, thermodynamics has been chosen as a study subject. In the following section, a brief outline of the course contents is provided in order to put the research study in context.

3.2.2 The course content of the participant universities

In order to make the course content manageable, it is divided into five headings. These headings are not restrictive, because many of them overlap with each other and alternative groupings are possible. The headings are:

- Gases and kinetic theory
- The first law
- The second and third laws
- Chemical equilibrium
- Chemical kinetics

In the following discussion each heading to described in terms f physical chemistry.

Gases and kinetic theory

This section starts by recalling the properties of gases. The idealised version of a gas called '*a perfect gas*' is given followed by details of how the equation of state is assembled. The states of the gases such as pressure, temperature, volume and amount of substance are described.

Students first encounter thermodynamics it is generally with **the zeroth law.** This states that '*if an object such as A is in thermal equilibrium with an another object B, and B is in thermal equilibrium with an third object C, then C is also in thermal equilibrium with object A'*. This law summarises the observed behaviour of bodies in contact with each other through diathermic walls. It is important because it allows us to build a thermometer, an instrument which shows the temperature change as a change in physical property. The section continues with the gas laws such as Boyle's law, Charles's law and Dalton's law. These laws lead to establishing the perfect gas equation. The kinetic theory of gases assumes that only kinetic energy of molecules contributes the energy of perfect gases. The potential energy of perfect gas molecules is assumed as zero. Since chemistry is an experimental science, it gains more importance because kinetic theory lets us experimentally determine the relationship between the properties of the gas. According to kinetic theory, *'the gas is modelled as a collection of mass points in continuous chaotic motion'* (Atkins, 1997; p.21).

Finally, the real gases, which do not obey the perfect gas law exactly, are presented. Real gas behaviour is better defined by an equation that takes into account intermolecular forces e.g. the van der Waals equation.

The first law

This section introduces some basic thermodynamics concepts such as system, surroundings, work and heat. Since thermodynamics concerns the transformation of energy, it is essential to define the boundaries between the system and the surroundings where the energy is transferred. This is not easy to accomplish for students and therefore it should be carefully defined where the system and surroundings start from. Once the boundaries are made clear, then energy transformations matters can be considered. Energy is transferred in different forms. These are defined as '*work*' and '*heat*'. These two concepts are crucial in chemistry and they have been widely researched using cross-age studies however the results have shown that they are vaguely understood. The main distinction between *work* and *heat* is seen not only in the system but also in the surroundings. **Work** can be defined as *energy transfer which causes the organised motion of atoms or molecules in the surroundings.* On the other hand, **heat** is *the energy* transfer *which causes the chaotic motion of atoms or molecules in the surroundings.* The definitions make clear that neither work nor heat is a form of energy, they are the transfer form of the energy. In addition, it is reemphasised that energy is conserved; neither being created nor destroyed, it is only transformed from one form into another as it is stated by the first law of thermodynamics.

Secondly, state and path functions are taught. The state functions those are that properties are independent of how a system is prepared and the path functions those are that properties related to the preparation of the state. Such properties, pressure and temperature, can be regarded as a function of variables and define the current state of the system.

Thirdly, the internal energy and enthalpy are explored. In thermodynamics the total energy of a system is known as **internal energy.** In other words, the energy which is transferred to the surroundings as heat or work in a closed system reflects the change in internal energy. **Enthalpy change** is defined as energy which is transferred as heat under the constant pressure. It is emphasised that the main difference between *internal energy* and *enthalpy* is that internal energy is the transfer of energy as heat under the constant volume and enthalpy change is the energy transfer as heat under the constant pressure. The section is followed by an introduction to a number of different types of enthalpy changes such as *phase transition*, *solution*, *ionisation*, *formation* etc. The section ends with the statement of Hess's law, and adiabatic systems.

The second and third law

This section concentrates on explaining the origin of the driving force of physical and chemical change. This driving force is **entropy** which is the measure of the number of ways that energy can be shared among the particles. The change in entropy can be calculated and the entropies of substances can be measured experimentally, irreversibility and the direction of spontaneous change are probed. **The second law** which states that *the entropy of an isolated system increases in the course of a spontaneous change* is explored. Two major applications of entropy, heat engines and refrigerators are then described.

The third law of thermodynamics is another central theme of this section. Under this heading, **the third law** is defined as; *all perfect crystalline substances, including compounds, have zero entropy value at zero Kelvin temperature scale.*

The section then concentrates on major thermodynamic properties in the systems such as Gibbs (free) energy and Helmholtz energy. After an introduction to Gibbs energy, it is emphasised that it enables the spontaneity of a process to be expressed alone in terms of the properties of a system instead of considering entropy changes in the system and its surroundings. That Gibbs energy enables us to predict the maximum work that process may achieve is also discussed.

The crucial difference between Gibbs and Helmholtz energy is the state of the system. If the change occurs at constant volume it is called Helmholtz energy, and if it occurs at constant pressure it is called Gibbs energy. **Chemical potential** which shows *how the Gibbs energy of a system changes when the substance is added to it* is also discussed.

Chemical equilibrium

In this section, spontaneous chemical reactions and the response of equilibria to the conditions such as pressure and temperature are discussed. When the Gibbs energy is plotted against the extent of the reaction, the fact that equilibrium compositions correspond to the minimum is one of the main characteristics. The notion that by locating this minimum it is possible to establish the relationship between the equilibrium constant and the standard reaction Gibbs energy is given.

How equilibria respond to changes in temperature and pressure is explored. At this point **Le Chatelier's principle**, which states that *a system at equilibrium when subjected to a disturbance responds in a way that tends to minimise the effect of the disturbance,* is discussed along with how equilibria responds to temperature changes for exothermic and endothermic reactions.

Chemical kinetics

The final section of the course covers reaction kinetics starting with the definition of reaction rates and measurement of reaction rates. Rate laws are stated and it is emphasised that reaction rates depend on the concentration of both reactants and products. The mechanism of deriving a rate law is also discussed. Finally, the rate determining step of a reaction, the steady-state concentration of a reaction intermediate, and how these concepts and techniques are applied to the simple systems such as enzyme kinetics and the elucidation of the mechanism of simple gas-phase reactions are discussed.

Concluding remarks to the content analysis

The analysis of the content of the physical chemistry course reveals that it is mainly dominated by thermodynamics. It forms an essential part of the course content. Since students experience difficulties in understanding thermodynamic ideas, it is worth investigating further. There are different aspects of the chemical thermodynamics which can be investigated. In this study only four basic thermochemical ideas are selected:

- Internal energy
- Enthalpy
- Entropy
- Gibbs energy

These were chosen because they are the fundamental chemical ideas in thermodynamics and students find them hard to understand at secondary level.

In addition, there is a lack of research about undergraduates' understandings of these ideas at tertiary level.

3.3 Developing Questions

In order to diagnose students' misunderstandings of the four key ideas listed above diagnostic questions were developed over several months including several revisions of content, wording, layout and drawings. Each question was discussed with Departmental colleagues, colleagues in Turkey and chemistry lecturers in the UK. In the next section the content of the trial questions will be explored.

3.3.1 The content of the prototype questions

In order to determine the content of the questions the important facts and definitions for each key ideas were established by consulting to the lecturers teaching the course in the participating universities. The facts were classified as should *know* or should *understand* according to the course content. These are listed below:

The facts and definitions students should know or understand about internal energy:

a) *know* that the total energy of a system is called internal energy.

b) *know* that the internal energy is the sum of the kinetic energy of all the particles and the potential energy arising from their interactions with one another.

c) *understand* that the internal energy change is the energy transferred as heat at constant volume.

d) *know* that the internal energy change of a system is equal to the heat gained or released in the system or work done by the system or on the system or both of them, and so *understand* that the internal energy of a system can be changed by doing work or by heating.

e) *know* that the internal energy cannot be measured directly but the internal energy changes can be measured directly by a calorimeter.

f) *understand* that for an perfect gas, the internal energy is directly proportional to the temperature of the gas because of the potential energy of an ideal gas is zero (the temperature increase in a system means that the internal energy of the system is increased).

g) *understand* that the internal energy of an isolated system is constant (First law of thermodynamics: we cannot create or destroy the internal energy).

h) *know* that the internal energy is a state property, which means that its value depends only on the current state of the system and is independent of how the system was prepared.

The facts and definitions students should know or understand about enthalpy:

a) *understand* that enthalpy change is the energy transferred as heat at constant pressure.

b) *know* that the enthalpy of a system cannot be measured directly but the change in enthalpy of a system can be measured.

c) *know* the idea of standard enthalpy of formation, $\Delta_f H^O$, of a substance is the standard reaction enthalpy for the formation of the compound from its elements in their reference states, and also *know* that the standard formation enthalpy of elements is zero in their reference states.

d) *know* that standard state of a substance at a specified temperature is its pure form at 1 bar (10^5 Pa).

e) *understand* the change in enthalpy of ionization, electron attachment, atomization, lattice, reaction, solution, dilution, hydration and activation.

f) *know* Hess's Law and understand that the enthalpy is a state property. The overall change in enthalpy is independent of the path taken from initial state to the final state. Therefore, a reaction enthalpy is the sum of the enthalpy of any sequence of reactions (at the same temperature and pressure) into which the overall reaction may be divided.

g) *understand* that the enthalpy change of a reaction depends on the overall strengths of the bonds of the reactants and the products.

h) *understand* that the enthalpy of the vapour at a certain temperature must be higher than that of the same amount of the liquid at the same temperature.

i) *know* that the enthalpy is an extensive quantity. This means that the enthalpy of a substance depends on the size of the sample.

j) *understand* that both endothermic and exothermic reactions can be spontaneous.

k) *understand* that change in enthalpy can be a guide to stability and the reaction feasibility but gives no indication of the rate of reaction (i.e. diamond is less stable than graphite).

The facts and definitions students should know or understand about entropy:

a) *understand* that entropy is a measure of the disorder of a system. Entropy is the measure of the number of ways that energy can be shared among the particles as well.

b) *understand* that the entropy is increased if we increase the number of ways of distributing the available energy among the particles, as well as the number of ways of arranging the particles in space.

c) *understand* that the entropy of a system increases as the temperature increases and when the substance melts and vaporises.

d) *know* that the entropy of a perfect crystal is zero when the temperature of the crystal is zero ($T=0$)

e) *understand* that substances have higher entropies if their molecules contain heavy atoms and large numbers of atoms.

f) *understand* that during a spontaneous change, the entropy of universe increases (The second law).

g) *be able to* calculate to change in entropy of the surroundings by using the temperature and the enthalpy change of the system.

h) *understand* that the total entropy change of the universe is zero for a process at equilibrium.

i) *understand* that the entropy of a system is a state property(function) that is directly proportional to the disorder of the system.

j) *understand* that any process that increases the number of particles in the system increases the number of microsystems, and it increases the entropy of the system.

The facts and definitions students should know or understand about Gibbs energy:

a) *know* the definition of Gibbs energy change ΔG, and *understand* that Gibbs energy change is the criterion of the spontaneity of chemical and physical changes at constant pressure.

b) *know* that the Gibbs energy change negative in a spontaneous change and positive value in a non-spontaneous change at constant pressure.

c) *know* that at constant temperature ΔG is related to ΔH, the entropy change ΔS and the temperature T by the equation $\Delta G = \Delta H - T\,\Delta S$.

d) *understand* that ΔH , although important, is not sufficient to explain spontaneous change (e.g. spontaneous endothermic reaction).

e) *understand* that the Gibbs energy change tends to became zero when the system approaches to the equilibrium and is zero at equilibrium.

f) *know* that the Gibbs energy changes with temperature, and that is given by $\Delta_r G^o = - RT \ln K$.

g) *know* that the standard Gibbs energy of formation of an element in its reference state is zero.

h) *understand* that thermodynamic quantities tell us nothing about the rate of the reaction.

i) *know* that the Gibbs energy is a state property (function).

j) *know* that for a system at equilibrium, neither the forward nor the reverse change is spontaneous, because both would lead to an increase in Gibbs energy (a decrease of total entropy).

k) *understand* that the magnitude of $\Delta_r G$ indicates how far the reaction is from equilibrium at a given composition.

l) *understand* that the more negative the value of $\Delta_r G$ indicates the more probably the reaction happens, and also the more negative the value of $\Delta_r G^o$, the bigger positive value of the reaction equilibrium constant, K.

By considering these basic facts and definitions, a hierarchy leading from internal energy to Gibbs energy is structured as shown in Figure 3.1.

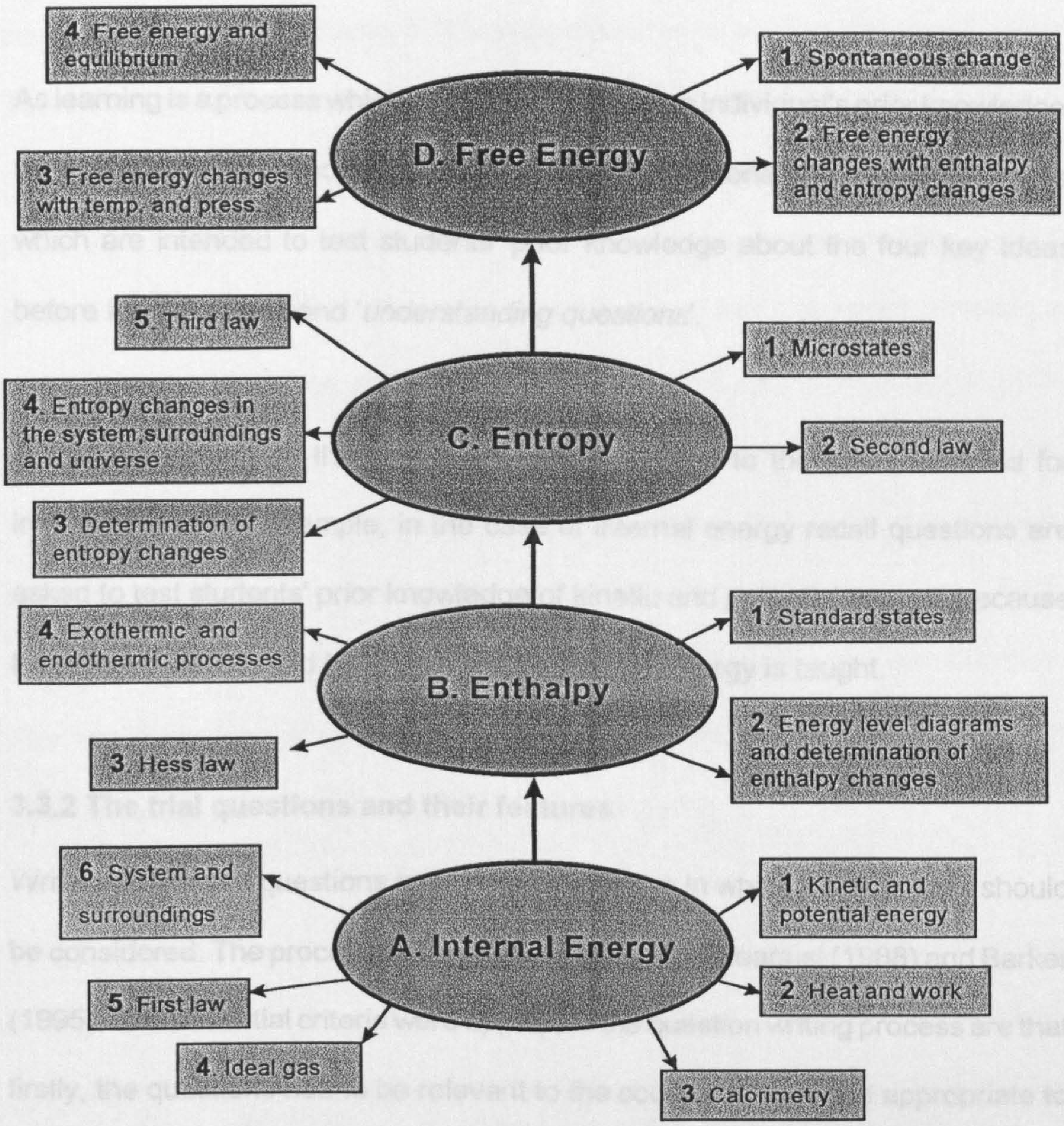


Figure3.1. Sequence of basic thermodynamics ideas leading up to free energy

The related concepts to the four key ideas are determined to keep the content to a manageable level. The hierarchy shows the ideas that should be known before learning internal energy, enthalpy, entropy and Gibbs energy. The questions were designed based upon this hierarchy, however it is not possible to prepare separate questions for every idea shown on the hierarchy as this would have produce a lengthy questionnaire. Some of the ideas have been selected to be tested during the interviews.

As learning is a process which is closely related to an individual's prior knowledge, the trial questions are composed of two types of questions; the *'recall questions'* which are intended to test students' prior knowledge about the four key ideas before learning them and *'understanding questions'*.

Recall questions test the simple key points related to the ideas selected for investigation. For example, in the case of internal energy recall questions are asked to test students' prior knowledge of kinetic and potential energy, because these two ideas should be known before internal energy is taught.

3.3.2 The trial questions and their features

Writing diagnostic questions is a complex process in which many factors should be considered. The procedure is well documented by Treagust (1988) and Barker (1995). The essential criteria were applied to the question writing process are that firstly, the questions had to be relevant to the course content and appropriate to third year undergraduate students. Hence, content analysis and concept hierarchy are performed and the questions are written in the light of this.

Secondly, it was thought that only one particular idea should be addressed in each question as this helps to prevent possible confusion during the analysis of written responses.

The third criterion was that the questions had to generate a broad range of responses. Here, the type of the question gains more significance. Because of the time limit and the difficulty in travelling overseas or piloting trial questions in Turkey more than once, two types of trial questions were developed. One type was composed of completely open ended questions, while the other type was dominated by the four multiple choice questions which were followed by an open ended explanation section. This was done to ensure that one would generate a broad range of responses and best fits the diagnosis of misunderstandings. Each question was given a specific name which was common to the two different versions of the same question. The number of trial questions was set high because there was no opportunity to repeat the exercise overseas. Each questionnaire was composed of 21 questions, some of which were asked in both versions. There were alternative questions which tested different thermochemical ideas or tested the same idea with different questions.

Draft questions were prepared and then circulated to colleagues in the Department in York. They were asked to comment on the structure, wording, drawings and especially the chemical contents of the questions and how chemistry undergraduates may answer them. In the light of these discussions, some questions were changed completely whilst others were modified. The ideas being tested within the questions are tabulated in Table 3.3. Here, each question's name and corresponding idea or ideas matched were according to the hierarchy. In the hierarchy, each key idea is represented with a capital letter such as A, B, C etc. and each related sub idea is given a number such as 1,2,3 etc. For instance A -1 means that this particular question tests ' kinetic and potential energy' related to internal energy and C - 2 stands for second law related to entropy. Some questions have multiple parts which test one idea in each part. The trial question packs can be seen in Appendix 1 which contains the multiple choice questions and Appendix 2 which contains the open ended questions.

Table 3.3 The content match of the trial questions

Name of the Question	Covered Topic in the Hierarchy
Copper (II) Sulphate	B - 2 and B - 4
Perfect Gases	A - 4
Energy	B - 4
Seawater	C - 4
Helium and Carbon Dioxide	A - 1
Potential Energy	A - 1
Explosion in a Steel Box	A - 5
Water	A - 2
Magnesium	A - 3 and B
Carbon Dioxide	C - 1 and C - 3
ΔG° and Temperature Change	D - 3
Two Spontaneous Reaction	D - 1
Spontaneous Change	C - 2
Gibbs Free Energy	D - 4
Hypothetical Reactions	B - 4
Mixing of the Gases	C - 1 , B and D - 2
Gibbs Free Energy Change with Temperature	D - 3
Gibbs Free Energy Change with Pressure	D - 3
Entropy Change	D - 4
Gibbs Free Energy Change	C - 4
Extent of Reaction	D - 4
Ice Melting	B - 2

3.4 The Pilot Study

The pilot study attempted to fulfill the following two aims. Firstly, to find out which question best satisfied the characteristics described in section 3.3.2. Questions which proved to be unsatisfactory would either be modified or not included in the final version of the questionnaire. Secondly, it was intended that a few interviews would be conducted following completion of the questionnaire for selected students to improve the author's interviewing skills. The interview strategy followed is described in section 3.5.3.4.

The pilot study was conducted in May 1998, before the end of second semester. This section describes how the pilot study was performed and re-examines the questions in terms of the range and types of responses generated.

3.4.1 Piloting the trial questions in the participant universities

Chemistry Education Departments from two different Turkish universities were asked to participate in the research study. One of them is established in western Turkey and the other eastern Turkey. In both departments, 21 third year physical chemistry students volunteered to take part in the pilot study. The number twenty one was a coincidence. The questionnaire was administered in class and students were asked not to confer or discuss their answers. Prior to completing the questionnaire, the students were informed about the research project and reassured that their responses would be remain confidential. Due to the length of the questionnaire there were some concerns about students being able to complete it and also that they might become tired towards the end of the time allowed. For this reason, the questions were put in a different order in different versions of the questionnaire. This ensured that answers were obtained for all questions. Students were allowed 100 minutes to complete the questionnaire.

Since the aim of the pilot study was to ascertain the suitability and the understandability of the questions, just after the administration of the questionnaire students were asked to assess the questionnaire, based upon the question by question discussion, by imposing the following questions:

- *Were the instructions clear?*
- *Was the question unclear or ambiguous? If so, will you say where is unclear or ambiguous? If you were became in my place how would you ask this question?*
- *Were the drawings helpful in understanding the chemical event in the question?*
- *Was the level of question appropriate for your level of knowledge?*
- *Was the question too easy or hard to understand?*

Questions were also asked about the general structure of the questionnaire:

- *In your opinion, has any major topic been omitted?*
- *Was the layout of the questions clear/attractive?*
- *Was the colour of paper pleasant?*
- *Did you object to answering any part of the questionnaire?*
- *Can you make any other comments?*

All the comments made by students on individual questions were assessed and a decision was made as to the question's inclusion in the final form of the questionnaire. During the pilot study, the content, layout, structure and wording of the questionnaire was also discussed with the lecturers who teach the physical chemistry courses in the participating universities.

Following the trial questions, students' responses were pre-analysed and five interviewees were chosen from each department.

3.4.2 Analysis of the results and conclusions derived from the pilot study

The coding scheme used to analyse the students' responses to the trial questions was adapted from the Abraham *et al.* (1992) study and is shown in Table 3.4.

Table 3.4 Coding scheme used for analysis of the pilot study results

The Pilot Coding Scheme		
Code	**Degree of Understanding**	**Criteria for Scoring**
1	No response	Blank I don't know I don't understand
2	No understanding	Repeats question Irrelevant or unclear responses
3	No understanding with specific misunderstanding	Response that include irrelevant or unclear responses and illogical or incorrect information
4	Partial understanding with specific misunderstanding	Responses that show understanding of the concept but also make statements which demonstrate a misunderstanding
5	Partial understanding	Responses that include at least one of the components of the validated response, but not all the components
6	Sound understanding	Responses that include all components of the validated response

During the analysis the following points were considered. The analysis was performed by comparing pairs of questions (since most of the questions were presented in the two formats), to see which format generated a wider range of responses. The percentage of the response rates, and what percentage of the students answered the particular question, were also considered. If a particular question was not answered by a large number of respondents or a large number of respondents answered it correctly, then it was eliminated. Moreover, the effect of the question content, layout and the diagrams or graphs in the questions were also considered during analysis. This was done by comparing students' comments about the questionnaire and their written responses. An extensive discussion of the students' responses and the analysis of the pilot study results are given in Appendix 7.

The pilot study provided some useful insights. The first insight was that time given to complete the questionnaires was too long. Most of the students completed the questionnaire earlier than expected taking on average 80 minutes to answer the whole questionnaire. It was also found that there was no significant difference in the time taken to answer the questionnaires composed of either the multiple choice or the open ended questions. Students spent an average of 4 minutes on each question.

Secondly, the discussion with students provided useful insights into the structure, content, layout and drawings associated with the questionnaire. Many useful points were highlighted and there were no negative comments about the content of the questionnaire.

Perhaps the most important and significant findings were concerning the interviews. It was the author's first interview experience and it assisted in identifying strengths and weaknesses of interview techniques.

3.4.3 The final questionnaire

After the pilot study had been performed and the results had been analysed the final version of the questionnaire was produced. During the analysis phase two major questions had arisen:

- *Which type of question?*

- *How many questions?*

From the analysis of the pilot study results, it became clear that open ended questions generated a broader range of responses than multiple choice ones. This can be seen from the analysis of results provided in Appendix 7. In some cases the multiple choice questions generated more correct responses but there was no explanation as why the particular option had been chosen. Students may have simply guessed the answer. Multiple choice questions generally lead the student to focus solely on the choices available and this narrows the range of explanations for their particular responses. Although open ended questions generated a broad range of responses, they also failed to get a response in some cases. Given the advantages and disadvantages of both type of questions, it was judged that open ended questions were more successful in diagnosing students' misunderstandings and therefore, it was decided to use them in the final questionnaire.

The next point to address was how many questions should be included in the questionnaire? As explained previously, 21 questions was considered too much for one session. It was apparent from the analysis of the results that some questions clearly failed, because more than half of the students left them blank and these questions were eliminated. Most questions were modified in terms of the wording, content, layout and drawings. Finally, seventeen questions were chosen for the final questionnaire. It was appeared that average of five minutes for each question would be enough and therefore seventeen questions was too much to answer all in one session. Hence, it was decided to divide it into two parts. By taking the equality into account, the final version of the questionnaire being prepared as two packages. They can be seen in Appendix 3 and 4. They were administrated as a pre-test at the beginning of academic year. The same questionnaire was also used as a post-test, but the letter at the beginning of the questionnaires was changed to explain the conditions at post-test. In Appendix 5 and 6 the Turkish version of the post-test questionnaires are also provided. The chemical ideas are being tested in each question and the expected answers for each question were also determined and can be seen in Appendix 8.

3.5. The Data Collection

In this section, the sample will be described along with how the questionnaire was administered and how the interviews were conducted.

The data collection was done in two phases. The first set of data was collected in October 1998, just after the beginning of the first semester in order to determine the students' knowledge of the selected ideas before the teaching started. This was important for this study, because what students knew affects the learning process for new ideas. It was thought that conducting a pre-test may help to identify students' understandings and misunderstandings of the selected ideas. The second set of data was collected in May 1999, just before the end of second semester.

3.5.1 The sample

In order to enhance the scope of the study, students from two different Chemistry Education Departments in Turkey were chosen. The initial aim in choosing the sample from Turkey was the consideration that the research study could be continued after the DPhil degree in the researcher's own country. Initially invitation letters were written to five different departments in Turkey with two of them agreeing to take part in the research. One of the participating departments is situated in western Turkey and the other is situated in eastern Turkey. The physical difficulties in travelling inside Turkey and limited time available to collect data were also important factors which affected the decision in choosing the sample.

The departments which took part in the research were coded with the capital letter of the city where they were situated. Therefore one of them is coded as '*Department B*' and the other coded as '*Department E*'. In both departments the academic year is composed of two 14 week semesters. The students in both departments are training to become chemistry teachers at high schools in Turkey.

The physical chemistry course is introduced in the third year of the undergraduate course in both institutions and the course content is also similar. In Department B the theoretical course and the laboratory course run parallel, while in Department E the physical chemistry laboratory course occurs in the following year; year four.

The sample was the third year students following the Physical Chemistry Course-I which was introduced in the first semester and Physical Chemistry Course-II which was introduced in the second semester. The number of students who took part in the research study is given in the following table.

Table 3.5 The number of the students completed the questionnaires

Students \ Department	Department B	Department E	Total
The number of the students who completed the OT_1	25	21	46
The number of the students who completed the OT_2	25	20	45
The number of the students who completed the ST_1	25	22	47
The number of the students who completed the ST_2	23	21	44

In Table 3.5; OT_1, OT_2, ST_1 and ST_2 refer to *Pre-test-I*, *Pre-test-II*, *Post-test-I* and *Post-test-II* respectively.

3.5.2 The administration of the questionnaires

The administration of the questionnaires was done in two stages. In the first stage, the questionnaires were administered in October 1998 as a pre-test. Although all the students on the physical chemistry course were asked to take part in the research, a few appeared not to do so voluntarily and they were eliminated from the study. Before administering the questionnaire, the questions in each set were put into different orders to ensure that every question got a similar number of responses. Also, different sets of the questions were printed onto different coloured paper to make them more easily distinguishable. The two sets of questions were also mixed together to ensure that they were answered by equal number of students in both departments. Students were allowed to answer the questions in one lesson, which was 50 minutes long. Before students started to answer the questions the research project was introduced by the researcher and they were assured that their personal information and responses would be kept confidential. The Pre-Test-I was answered by 46 students and 45 students answered the Pre-Test-II. At the second stage 44 students answered the Post-Test-I and Post-Test-II was answered by 47 students. The students who were not in the class at the time the study was carried out were not asked to answer the questions later.

Following the Post-Test, in order to find out students' perspectives on learning difficulties in physical chemistry and their thoughts about the how to overcome these difficulties they were asked to work in small groups, to discuss the reasons why they found it hard to understand ideas in physical chemistry. They were asked to write them on the sheet provided (see the questionnaire sheet in Appendix 9). They also were asked to discuss and write down how the learning difficulties might be overcome. Informal interviews were also carried out in which some of the students raised concerns and some anecdotal evidence was recorded.

Shortly after the questionnaires were completed, a surface analysis of the results was done and possible interviewees were identified. The interview strategies are reported in the following section.

3.5.3 The interviews

A number of interviews were carried out just after the pre-test and the post-test to support the data obtained from the questionnaires. The interviews held after the pre-test sought to reveal the students' understanding of the four selected ideas and related ideas such as internal energy, enthalpy, entropy and Gibbs energy. The interviews after the post-test sought to explore the students' understandings of a particular idea in detail. In total, 47 selected students were interviewed. In addition two lecturers were also interviewed about the possible sources of the students' learning difficulties and possible solutions to these difficulties. This section discusses the purpose of the interviews, describes how interviewees were selected and explains the interview strategy employed.

3.5.3.1 Pre-interviews (interview about all ideas)

Pre-interviews with 22 students were carried out in October 1998. The purpose of the pre-interviews was to explore students' knowledge about internal energy, enthalpy, entropy, Gibbs energy and related ideas such as potential energy, kinetic energy, heat, temperature, work and spontaneity at the beginning of the course. Therefore, they have been called *interviews about all ideas* for the purposes of the study. This is important because students bring misunderstandings with them into the classroom and previous knowledge plays an important role in learning new ideas. *'The constructivist learning theory proposes that students actively construct new meaning by using their present conceptual frameworks to interpret new information in ways that make sense to them'* (Garnett *et al* 1995). Therefore it is important to establish what knowledge students bring into the classroom.

3.5.3.2 Post-interviews (interview about an idea)

Post-interviews were carried out with 25 students in May 1999 following the post-test. These interviews explore the students' understanding of the one particular idea in detail. As there were four ideas chosen to be studied, internal energy, enthalpy, entropy and Gibbs energy, interviews were focussed on students' understanding of these ideas. Among the 25 interviewees, six of them were interviewed about internal energy, seven about enthalpy and entropy respectively and finally five of them were interviewed about Gibbs energy. The interviews were based upon the facts determined in section 3.3.1 and the students' understandings of the particular idea were questioned in detail.

3.5.3.3 Interviews with the lectures

Two lecturers who had taught the physical chemistry course in the participating universities were interviewed after the post-test in order to establish their views of learning difficulties in physical chemistry and their possible solutions. The interviews were unstructured and started with an introductory question:

> *'What do you think makes it hard for the students to understand chemical ideas in physical chemistry?'*

Subsequently they were asked about the issues raised by during the interviews. The interviews were carried out in the lecturers' offices and lasted about an hour. One of the lecturers agreed to have the interview tape recorded and notes were taken in the case of the other lecturer.

3.5.3.4 The interview strategy

The interviewees were selected on a voluntary basis including the consideration of their responses to the questionnaire. The respondents did not answer the questionnaire at all were also eliminated because it was considered that they may not have enough knowledge of the idea/s being studied.

Once the interviewees were selected, appointments were made with individual students by the researcher. They were not told about the content of the interviews, but in general, they were aware that the interviews would be in the same vein as the questionnaire.

Interviews took place on a one-to-one basis, usually in an office or in an empty laboratory and students' permission to tape-record the interview was sought in each case. Interview times varied between half an hour and 45 minutes. At the beginning of each interview, students were given a brief explanation of the aims of the interviews and they were put at their ease by adopting a relaxed approach. With a few exceptions, interviewees were willing to talk and did so freely, others needed encouragement and gentle prompting. As the interviews aimed to explore students' understandings of particular idea/s, students were encouraged to talk in a non-confrontational way. Interviews were semi-structured, and no prepared sets of questions were used. However the interviews were conducted with reference to the knowledge and understanding students were expected to develop (see section 3.3.1). Interviewees were asked to talk freely on what they knew about the particular idea chosen and follow-up questions were asked according to the interviewees' responses in the light of the pre-determined facts as are given in Section 3.3.1.

The interviews provided a rich source of data. As well as supplementing the questionnaire data they also revealed several misunderstandings which had not emerged from the questionnaire data. Although the interviewees were asked not to reveal the content of the interviews to the following interview candidates, some of the interviewees appeared to come to the interviews prepared. This was not considered as a threat to the reliability and validity of the interview since students did not know which particular questions they were going to be asked about in their interviews.

3.5.3.5 Limitations of the research methods used

Two main limitations in the research methods used emerged. The first concern arose from the use of the same questionnaire as the pre and post-test. There is a possibility that students might remember questions from the pre-test and therefore this would give them an advantage at the post-test. However, there was a long interval between the pre-test (administered in October 1998) and the post-test (administered in May 1999) and it was considered that this interval was long enough to ensure that students did not recall the detail of the previous questionnaire. Students were told that they would be asked to answer similar kinds of questions at the end of academic year, but they were not told that the questions would be the same. In addition, there were two packs of questions each containing different questions, therefore the chance of answering the same questions at the pre and the post-test was reduced.

The second limitation was that the interviews had to immediately follow the completion of the questionnaire, therefore there was no time to analyse the students' written responses in depth and determine any points which could be clarified during the interviews. Therefore interviews were conducted on the basis of facts about the ideas determined that what students should know and understand given in section 3.3.1. However, before the interviewees were chosen a superficial analysis of the students' writings was done and the interviewees were chosen accordingly. For example, if a student was not a volunteer for an interview they were eliminated. Also if a student did not respond to the overall questionnaire they were eliminated because might be unwilling to take part in the research or they might not have sufficient knowledge of the subject.

3.6 Data Analysis

Having described the development of research tools and data collection, it is now possible to look at the data analysis. This section describes how the coding scheme developed and how analysis of the data was carried out. In this study, the word '*response*' refers to the whole answer given for a single question in the questionnaires. Therefore it may both include both scientifically correct and incorrect ideas as well as misunderstandings. In addition, '*respondents*' refers to the students who completed the questionnaire.

3.6.1 Development of the coding scheme

Once the first data collection had been done, the responses needed to be analysed. Every page of an individual's response was given a number to uniquely identify it and questionnaire pages were detached and the responses given to the same questions were put together. Then the responses were skimmed and possible coding schemes were considered. From this superficial analysis it emerged that there was a considerable number of responses which included both understandings and misunderstandings. In addition, there were responses that included multiple misunderstandings in the same response and this fact played an important role in developing the coding scheme.

In the process of the development of a coding scheme two factors were considered. Firstly, the students' responses needed to be analysed in a systematic way using a common coding scheme which could be applied to all 17 questions.

Secondly, since one of the purposes of the research was to identify the students' misunderstandings, the coding scheme had to be able to identify individual misunderstandings and how widespread they were. The coding scheme used to analyse the pilot study results needed to be developed in order to allow for the identification of individual misunderstandings. The first idea was to develop a coding scheme which had general categories which could be applied to all questions and sub-categories which could be changed according to the individual question content. For this purpose, initially, two similar coding schemes were developed by adopting the pilot coding scheme. These are called the *Early Coding Scheme (1)* and *Early Coding Scheme (2)*. These two coding schemes were shown Table 3.6 and 3.7.

The responses given to the question called *Potential Energy* were analysed by using the two coding schemes separately. The reason why *Potential Energy* was chosen was that it generated a wide range of responses including both understandings and misunderstandings. The following results emerged from the early analysis of the results. It seemed that responses fitted better to the Early Coding Scheme (1) because in the Early Coding Scheme (2) there was no category into which individual misunderstandings could be placed. It appeared that it only categorised the responses into the groups rather than identifying the

Table 3.6 Early coding scheme (1)

Early Coding Scheme (1)	
Code	**Description**
1000	Blank
1100	Repeat the question
1200	Uncodeable
2000	No understanding the tested chemical idea
2100	Understanding only some aspect/s of the tested chemical idea
2200	Sound understanding the tested chemical idea
3000	Evidence for previously identified misunderstandings
3100	Evidence for new specific misunderstandings related to the tested chemical idea
3200	Evidence for new specific misunderstandings related to the general chemical knowledge

Table 3.7 Early coding scheme (2)

Early Coding Scheme (2)	
Code	**Description**
1000	Blank
1100	Repeat the question
1200	Uncodeable
2000	No understanding the tested chemical idea
2100	No understanding the tested chemical idea and also shows previously identified misunderstandings
2200	No understanding the tested chemical idea and also shows new specific misunderstanding related to the tested chemical idea
3000	Partial understanding the tested chemical idea
3100	Partial understanding the tested chemical idea and also shows previously identified misunderstandings
3200	Partial understanding the tested chemical idea and also shows new specific misunderstanding related to the tested chemical idea
4000	Sound understanding the tested chemical idea

misunderstandings. Therefore it was eliminated and further efforts were focussed on how to improve the Early Coding Scheme (1). In order to do this, Early Coding

Scheme (1) was applied to five questions test the students' understandings of internal energy and related ideas. The following results emerged from this analysis.

Firstly, four digits were used in the early coding scheme to code the responses. The first digit identifies the general groups, the second one identifies the main categories and the third and fourth digits identify the sub-categories which emerge from different questions. Initially, it was estimated that there may be more than ten sub categories for some of the main categories, therefore two digits were allocated to the sub-categories . After application of the early coding schemes to real data, it emerged that this was unnecessary since there were no more than 10 sub categories so there was no need to use four digits. Secondly, there was no need for the category called '*Repeat the question*' since none of the respondents repeated the statements given in the questions. Also it was decided that there was no need to separately categorise the misunderstandings which were previously identified by the other researchers. Instead it was decided to report these in the other misunderstandings categories and clarify this in the related text. Thirdly, it was thought that it would be better to make some changes in the wording of the statements such as using the phrase '*specific chemical idea tested in the question*' instead of using the phrase '*the tested chemical idea*' to emphasise and clarify the tested chemical idea. Fourthly, it was considered that it would be better to put the categories in an order from blank to sound understanding. Several modifications have been done in the light of the above considerations. Then the final coding scheme can be seen in the following table.

Table 3.8 The final coding scheme

Code	Description	Criteria for Scoring
00	**Blank**	***No response / blank***
10	**Uncodeable**	***Responses that could not be fitted any of the categories***
20	**No understanding of the specific chemical idea tested in the question**	***Irrelevant/unclear responses, irrelevant / incorrect formulas or explanations relating to the specific chemical idea tested in the question***
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	***Responses that show only one / more than one or major aspects of the validated chemical ideas relating to the tested idea***
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	***Responses that show scientifically incorrect or illogical information which is labelled as misunderstanding relating to the specific chemical idea itself tested in the question***
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	***Responses that include misunderstanding relating to the general chemical / scientific knowledge***
60	**Sound understanding of the specific chemical idea tested in the question**	***Responses that include all components of the validated responses and also show no misunderstandings***

Table 3.8 shows the final categories and descriptions of them. It was decided to code the misunderstandings related to the specific chemical idea tested in the questions and the misunderstandings related to the general chemical or scientific knowledge separately. This was because some of the misunderstandings identified were not related to the specific chemical idea but were related to the general scientific or sometimes the chemical knowledge. Since the study intended to identify and classify undergraduates' misunderstandings about the four basic thermodynamic ideas, it was thought that it would be better to distinguish the misunderstandings related to a specific chemical idea tested in the question from the others.

3.6.2 The analysis of the questionnaire data

Once the coding scheme was developed, the analysis needed to be performed. The categorisation and analysis began after the second data collection, and the pre and post-test responses were analysed together question by question. The analysis was done in five stages which are described below.

All the responses given to a particular question were analysed and partial understandings and misunderstandings were identified and noted. This allowed the preliminary coding table for the particular question to be formed so as to tally with the responses. In the preliminary coding table an extra space was also left in case of some partial understanding or misunderstanding that was not previously identified. The responses given to a particular question were tallied. If new misunderstandings or partial understandings were detected at this stage they were also added to the preliminary coding tables. Also, the codes for each student's response were recorded in another table in order to be able to see an overall picture of the results. This also allowed students' individual responses to be recalled at a later stage. These tables and the coding tables were kept together and used during writing of the results.

Some modifications were done on the coding tables, particularly where similar misunderstandings which had been categorised into different codes were combined. In addition, the labelling of the sub categories was modified in cases where it was considered appropriate. Finally, the numbers were put into the tables and the percentages were calculated. At this stage, if any of the misunderstandings were identified in less than five percent of respondents they were eliminated from the tables. The final coding tables can be seen in chapters 4, 5, 6 and 7.

3.6.3 The analysis of the interview data

The interview data was used to enhance the questionnaire data. All the tape recorded interviews were transcribed into written form and a copy made. The analysis of the interview data was done by reading all the transcripts and underlining the detected misunderstandings. Although some misunderstandings were identified from the interviews alone, a number of misunderstandings which were identified by the questionnaires also appeared during interviews. This data was used to support the questionnaire data.

3.6.4 Validity and reliability issues

The validity of the data analysis was considered during the development of the coding scheme and the analysis of the questionnaire and interview data. During the development of the coding scheme, it was recognised that it is possible to analyse the same data in different ways, however, it was considered that the best method of analysis which suits to the data collected was utilised. The early coding scheme was applied to five questions and modifications were made as required before forming the final coding scheme. Also, during the development stage, discussions were held with colleagues in the department about the proposed coding scheme as well as about the alternative coding schemes.

When it comes to the reliability of the data analysis, a difficulty faced was the fact that the data was in Turkish and there were only a limited number of ways to improve the reliability of the data analysis. The reliability of the data analysis would be improved by asking an expert in the same research area to code some of the data and compare the results. This unfortunately was impractical since there was no expert in the area in England who could speak the Turkish language. Another option would have been to translate some of the data into English and ask some of the colleagues in the department to code the same data and compare the results. However there was a danger that some of the sense of the responses would be lost during translation.

A further option was to re-code the same data after a period of time. In order to improve the reliability of the data analysis, responses were given to five questions which related to internal energy and related ideas were re-coded after six months without reference to the previous coding tables. The results showed over 90% repeatability. This was thought to be the most practical way of enhancing the reliability of the coding in the circumstances.

3.7 Conclusions

This chapter has set out how the research was planned and designed, how the questionnaire was developed and how the pilot study was conducted. In addition, the strategies applied during data collection have been explored. Finally, the data analysis has been described and the validity and reliability issues discussed.

The next chapters will be looking at the students' understandings of the selected thermodynamic ideas.

Chapter 4

Chapter 4

Analysis of The Responses About *Internal Energy and Related Ideas*

This chapter is the first of five presenting the data which was obtained in the research study. The responses to five questions about internal energy and related ideas, *Potential Energy, Helium and Carbon Dioxide, Perfect Gas, Explosion in a Steel Box and Water,* are analysed and discussed. The analysis has been done using the coding scheme developed (see section 3.6.1). Each question is discussed separately and main sections titled with the specific name of the questions used in the questionnaire.

The responses for the pre and the post-tests were coded and tabulated. They are presented in the same table in order to provide a concise summary of the results. In the tables, *f* donates the frequency which refers to how many times the particular idea was identified. The word *'response'* refers to the whole answer given for a single question. It may include both scientifically correct and incorrect ideas as well as misunderstandings. The main categories are highlighted in bold and are the same for all questions. Sub-categories vary according to each particular question. The total number of respondents are also indicated in the tables. Percentages are calculated to help illustrate how often particular misunderstandings or partial understandings were repeated. The totals may exceed 100% in some cases, because some responses included more than one misunderstanding and partial understandings which were coded into different categories. For example, if a particular response included two different misunderstandings and one partial understanding it was coded three times in three categories. In contrast, some of the total percentage figures may be less than 100. This is due to the exclusion of misunderstandings that occurred with a frequency of less than 5%. Since misunderstandings occurring at a frequency of less than 5% were made by only two respondents, it was decided to exclude these from the tables.

In the text, quotations taken from students' written responses are identified with codes such as $OT_1/E/S_1$ or $ST_1/B/S_1$. In this codes, **OT** and **ST** stands for the pre and the post-tests respectively, B and E indicates the department and S indicates the students number. For example, $OT_1/E/S_1$ indicates that quotation from a response that was given for a question from the Pre-Test-I by a student in department E, and S_1 indicating the students' number which is 1 in this case. The name of the questions were not addressed in this code since the analysis has been done question by question. In addition, in the extracts from the interviews, **R** stands for *the researcher* and **I** stands for *the interviewee*. Similar to the questionnaires **OI** and **SI** refers to the pre and post-interviews. For example $OI/B/S_1$ refers to an extract is taken from the pre interview with the first interviewee from the Department B. However it should be noted that the students coded with the same number in questionnaires and interviews are not the same. In the following section the results will be discussed separately for each question.

4.1 Potential Energy

This question probes students' ideas about potential energy which contribute to internal energy. Potential energy is a fundamental idea in science and therefore it should be clearly understood before internal energy has been taught. This question (see section 3.6.1) tests the fact that potential energy of a perfect gas is assumed to be zero. In order to understand this basic fact, students should know what potential energy is and how it would be applied to a particular situation of a perfect gas in chemistry.

The potential energy of a body (such as be an electron, a nucleus, a particle, an atom or a block of matter) is the energy due to its position. For a system to have potential energy, two conditions must be fulfilled; firstly there must be a force field in operation and secondly work must be done against the force field to put some part of the system in an unstable position. "Raised weight" is just a special case of potential energy, in which the force field is gravity and the unstable position is up (Maple,1996, p.40).

In the question the source of the potential energy of the gas particles is the attraction and repulsion forces between the gas molecules or atoms. When a charged body is in the vicinity of another charged body, it acts on the charge carried by the body and they have potential energy. Also, when two real gas particles collide they lose some of their kinetic energy and it is stored as potential energy in the body of the collided particles. However, it is assumed that there is no interaction between ideal gas particles and it is assumed that if they collide these collisions are perfectly elastic in which energy transfer (i.e. from kinetic to potential energy) does not occur. In an elastic collision the sum of the kinetic energy of the colliding particles is the same before and after the collision therefore, ideal gas molecules or atoms are assumed as having zero potential energy. Students' responses to *Potential Energy* in the pre and the post-tests were summarised in Table 4.1.

Table 4.1 shows that about one in three of the responses were blank at the pre-tests while this proportion dropped to around one in five (18%) at the post-test. A few of the responses were uncodeable, and a small number of respondents demonstrated no Understanding of the specific chemical idea tested in the question.

Table 4. 1 Analysis of the students' responses to ***Potential Energy***

Code	Description	Pre-test (n=45)		Post-test (n=44)	
		f	%	*f*	%
00	**Blank**	14	31	8	18
10	**Uncodeable**	2	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	1	-	1	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	26	58	32	73
31	The specific volume of the ideal gas particles is negligible	3	7	9	20
32	There is no interaction between the ideal gas particles	12	27	21	48
34	Ideal gas particles make elastic collisions	4	9	1	-
34	At low pressures and high temperatures gases get closer to the ideal conditions	7	16	1	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	12	27	15	34
41	Potential energy is zero because ideal gases have no volume	5	11	7	16
42	Potential energy is related to the position of the particles in space	3	7	2	-
43	Potential energy is related to the mass/weight of ideal gas particles	3	7	2	-
44	Potential energy is zero because ideal gas particles have maximum/minimum velocity	1	-	4	9
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	4	9	1	-
51	Gases get closer to the ideal conditions at high pressures and low temperatures	4	9	1	-
60	**Sound understanding of the specific chemical idea tested in the question**	1	-	3	7

Table 4.1 also shows that, in total, 58% and 73% of the responses given to the pre and the post-tests respectively demonstrated partial understandings of the chemical idea tested in the question (coded as 30). These were the highest figures among the categories for this question. Partial understandings were grouped under four main headings. These can be seen from Table 4.1 for the pre and the post-tests respectively, which followed *the specific volume of the ideal gas particle negligible* (coded as 31) 7% and 20%, *there is no interaction between the ideal gas particles* (coded as 32) 27% and 48%, *ideal gas particles make elastic collisions* (coded as 33) 9% and seen only in one case, and finally *at low pressures and high temperatures gases get closer to the ideal conditions* (coded as 34) 16% and seen only in one case.

All the partial understandings were related to the properties of perfect gases. These ideas come from the kinetic molecular theory which outlines the main characteristics of perfect gases (usually called ideal gases by the course tutors in Turkey, therefore "perfect gas" and "ideal gas" will be used interchangeably in the following sections) as seen in these examples:

> *There is no interaction between ideal gas molecules. They are such a gas that there is no repulsion and attraction forces, and assumed as having zero specific volume...* $(ST_2/B/S_{14})$
>
> *Ideal gas molecules have no interaction between each other. Neither are they considered as having repulsion or attraction forces nor considered having specific volume. They are accepted as point like molecules and their collisions are elastic...*$(OT_2/B/S_{11})$
>
> *When we say ideal gas , I consider high temperature and low pressure. Because gases reach high diffusion capability at high temperature and low pressures...*$(OT_2/E/S_{12})$

The majority of the respondents attempted to give facts about perfect gases rather than an answer to the question. The number of facts related to perfect gases increased in the responses at the post-test. This may be because students memorise the facts rather than applying them. The responses suggest that students find it hard to explain the potential energy of a perfect gas particle, possibly because it is a highly abstract idea and they are not able to apply their knowledge to a perfect gas situation. Alternatively, they may have inadequate knowledge of the energy of a body in chemistry.

About one third of the responses for both the pre and the post-tests, showed misunderstandings about potential energy and perfect gases. The identified misunderstandings and their frequencies can be seen on Table 4.1. The misunderstandings fell into four groups. In the first group students believed that *the potential energy is zero because ideal gases have no volume* (coded as 41). This was the most common misunderstanding and appeared in 11% of the pre and 16% of the post-test responses. Some of the students *related the potential energy to the position of the particles in the space* (coded as 42) and some also *related the potential energy to the mass/weight of the ideal gas particles* (coded as 43). Both misunderstandings, 42 and 43, were observed in 7% of the pre-test but only in two cases at the post-test. A further misunderstanding (coded as 44) was that *the potential energy is zero because ideal gas particles have maximum/minimum velocity* was identified in only one response at the pre-test but its percentage increased to 9% at the post-test.

There were some misunderstandings that were observed only in one or two responses which are not reported in the table but listed below:

- *Potential energy is zero because there is no heat transfer between ideal gas particles*
- *Ideal gas particles do not do vibrational, rotational and transnational movements*
- *Potential energy turns to kinetic energy when gas particles collide to the inner surface of container*
- *If there is no interaction between the particles they do not have any kind of energy*
- *Gas molecules have a constant energy value*

Only one response showed sound understanding of the specific chemical idea tested in the question at the pre-test, while this increased to three responses in the post-test. Such a low percentage of answers showing sound understanding is acceptable in the pre-test. Again, a low level of understanding in the post-test is most likely because it was taught at the first semester and most of the students were not able to remember it during the post-test which took place at the end of the second semester. It clearly shows that students are more likely to memorise the fact just for passing exams and will not pursue it further afterwards. In the following sections the misunderstandings most commonly observed will be discussed.

4.1.1 Potential energy is zero because ideal gases have no volume (41)

> *Ideal gases assumed that they have no volume and also no intermolecular repulsion and attraction forces. If a gas has no volume, it cannot be expected having potential energy (OT_2/B/S_8).*
>
> *... Ideal gases haven't got volume. They are point like particles...therefore they have zero potential energy (OT_2/B/S_{24}).*
>
> *It is supposed that ideal gas molecules have no volume. Therefore, if they have no volume it is impossible to talk about their potential energy (ST_2/B/S_{17}).*

This was a common misunderstanding and possibly originates from the misunderstanding that *ideal gases have no volume.* In fact all gases have the same volume as that of the container which they fill. The fact is that, ideal gases are not a real gas and all the facts about them are derived from a list of assumptions: that they have no specific volume, that they make elastic collisions and that they are point-like particles according to kinetic molecular theory. By stating that ideal gases have no volume, some participants might be referring to either the specific volume of particular gas molecules or whole volume of the ideal gases but this was not clear from the responses which one was intended. However, it is clear that students have difficulty with ideal gases and facts about them.

4.1.2 Potential energy is related to the position of the particles in space (42)

This was a rare misunderstanding at the post-test but more common in the pre-test. The reason for this misunderstanding might be the idea taught in secondary education in physics courses in which potential energy is defined as the energy that a body possesses as a result of its position.

> *... It is not possible to consider an ideal gas molecule at a certain level from the ground,... therefore they have been assumed having zero potential energy(ST$_2$/B/S$_4$).*

As quoted it is clear that students confused the gravitational potential energy and coulomb (electrostatic) potential energy. Perhaps this was the major root of the misunderstanding.

Another response was that potential energy is zero because the particles were fixed in space or somewhere else inside the container. The following quotation illustrates this:

> *...and also potential energy is the energy of the stationary (the word used in the Turkish means fixed somewhere in space or in a container) molecules. It is impossible that ideal gas molecules can be fixed anywhere, so their potential energy must be zero. (OT$_2$/E/S$_{18}$).*

The respondent attempted to apply the definition of potential energy used in physics that *potential energy is the energy a stationary body possesses.*

4.1.3 Potential energy is related to the mass/weight of ideal gas particles (43)

In this case, responses were combined together based upon the words *mass* and *weight* because these are terms that students tend to use interchangeably. As these concepts do not form a part of this study, they will not be discussed here, however same typical examples are shown here:

> *It is considered that ideal gas molecules have no weight...and therefore their potential energy becomes zero (OT$_2$/E/S$_4$).*

As can be seen the respondent attributed the potential energy of gases only to its weight. Also s/he argued that ideal gas particles have no weight and therefore concluded that they must not have potential energy either.

In the responses in the post-test similar misunderstandings were revealed:

> *...Potential energy of a body (m.g.h) is due to its weight, and also ideal gases are assumed as having no specific volume. Therefore their potential energy (PE = 0) is zero (ST$_2$/B/S$_1$).*
>
> *Because: the mass of the ideal gases is assumed as zero. Thus, their potential energy becomes zero, m.g.h = P → 0.g.h = 0 (ST$_2$/B/S$_{16}$).*
>
> *Let's remember formula of potential energy, E_p = m.g.h (1),*
> *and m (mass) = d(density) x V (volume) (2). In ideal gases volume is zero (V = 0).*
> *Therefore, equation 2 becomes zero and then equation 1 becomes zero (ST$_2$/B/S$_{22}$).*

In the final quotation, it is clear that students make misjudgements because of considering that ideal gases have no volume and then this is followed by some mathematical calculations which lead to the misunderstanding. In the first quotation the respondent made the mistake of writing the equation of potential energy. It is possible that this is a result of carelessness or straight memorisation of the equation without understanding it.

4.1.4 Potential energy is zero because ideal gas particles move with a maximum/minimum velocity (44)

This particular misunderstanding was identified only in one of the pre-test responses but its frequency increased at the post-test. This may result from considering the kinetic and potential energy of perfect gases together, because when a particle falls it loses its potential energy which transfers to kinetic energy.

> *Ideal gas particles move with a maximum velocity, and their kinetic energy must be maximum. When kinetic energy becomes maximum potential energy must be minimum (OT_2/B/S_{16}).*
>
> *It is considered that ideal gases have maximum velocity. Therefore their kinetic energy is maximum (and so potential energy is minimum) (ST_2/B/S_5).*

Another relevant consideration is that ideal gas conditions can be obtained at high temperatures and low pressures. If a gas is an ideal gas, it must be at a high temperature and at a low pressure where the velocity and kinetic energy is thought to be the highest. Perhaps the respondent thought in that way and reached the conclusion that ideal gas molecules have maximum velocity and kinetic energy.

Conversely some students thought that ideal gas particles have minimum velocity and energy values and therefore their potential energy must be zero or close to zero. This kind of approach is more likely due to misunderstanding of the ideal gas conditions discussed in section 4.1.5.

4.1.5 Gases get closer to the ideal conditions at high pressures and low temperatures (51)

This is the most common misunderstanding identified in 9% in the pre-test but dropped to only one response at the post-test. Many of the students initially thought that ideal conditions could be obtained at low temperatures and high pressures. At pre-interviews some students also displayed other misunderstandings about the definition of an ideal gas. The following discussion represents typical misunderstandings.

> *R: Could you tell me how do you define ideal gases? What are ideal gases do you think?*
>
> *I: Ideal gas...(long silence) when pressure becomes zero, I mean its pressure is zero.*
>
> *R: Can you tell me a little bit more about what you mean by zero pressure? What happens when the pressure becomes zero?*
>
> *I: When pressure becomes zero the gas doesn't move, because to produce pressure it must move and collide with the walls of the container. If the pressure is zero then that means that it is motionless. Therefore potential energy of ideal gas is zero.*
>
> *R: Ok. I understood what you mean. What about the kinetic energy of ideal gases? What do you think about it?*
>
> *I: ...(pause) it was not moving, ideal gas, so if it is not moving it shouldn't have kinetic energy either. (Pause) I think it has potential energy but no kinetic energy...(OI/E/S_7).*

The interviewee appeared to misunderstand the ideal gas conditions, which are obtained with low pressure and high temperature and exhibited different misunderstandings like they are motionless or have zero pressure. Later on the interviewee also struggled with the potential and kinetic energy of ideal gases. A considerable number of interviewees (over half of them) showed similar poor understanding of ideal gases.

4.1.6 Discussion

Although it is difficult to give a single definition for potential energy because it depends on the mode of interaction (the type of field) that the body experiences, there are two definitions. The first one as discussed in section 4.1, is *gravitational potential energy* which is the most commonly definition and it is the energy of a body in the gravitational field of the Earth. This is arbitrarily zero on the surface of the Earth. The second one is the *coulomb potential energy* which has a greater importance in chemistry. It is the potential energy of a charged body in the vicinity of another charged body in an electric field (Atkins 1997, pp.4-5). The second definition is more commonly applied in chemistry because it deals with the interactions between tiny particles such as ions and electrons.

Potential energy is first introduced in science lessons in secondary school in physics. It is mostly considered as gravitational potential energy which is the energy of a body possesses due to its position where there is a gravitational force on it. It is easier for students to understand this definition because of the many real life examples such as lifting a book, dropping chalk or a ball. This was confirmed by the interviews where almost all of the interviewees defined potential energy from the physics point of view:

> *R: Could you tell me what you know about potential energy?*
>
> *I: It is the energy that an object does against gravitational force, for example, if we lift an object we do work against and it gains potential energy (OI/B/S_2).*

When students experience the idea of the potential energy in chemistry, they attempt to utilise their existing knowledge of potential energy learned in secondary school. In chemistry learning requires a more abstract approach and potential energy is something that only exists in our thought as Duit (1987) states. Potential energy is concerned with tiny particles and the repulsion and the attraction forces between them which cannot be observed with the naked eye. At this point, if the connection between the existing knowledge and the new information is not made in a proper way misunderstandings occur. The results of this study suggest that students could not associate the definition of potential energy with the relevant discipline.

Possible sources of misunderstandings identified might be the two aspects of potential energy given at the beginning of the section. Despite the fact that both definitions are given in undergraduate chemistry textbooks, most of the textbooks used in secondary education include the definition of gravitational potential energy only. Once students learn about potential energy from this aspect, it persists at more advanced level and it is hard to change it. Therefore their knowledge can seem to be inadequate and further misunderstandings can develop. Identification of the similar percentages of misunderstandings in both the pre and the post-tests also supports the above approach. Perhaps such vital ideas should be given extra consideration when they are first introduced to the students in secondary school.

4.2 Helium and Carbon Dioxide

Helium and Carbon Dioxide tests the fact that average kinetic energy of gas molecules is the same at the same temperature. In order to reveal the undergraduates' misunderstandings explicitly, the question was asked in two different forms. In the first form the sub-question **(a)**, two different gases were given with the same volume and physical conditions. In the second, the sub-question(**b**), the same gas was given, but this time the volume of the containers was changed. The question and expected answers can be seen in Appendix 8.

Table 4.2 Analysis of the students' responses to *Helium and Carbon Dioxide*

Code	Description	Pre-test (n=46)				Post-test(n=47)			
		a		b		a		b	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	3	6	4	9	4	8	6	13
10	**Uncodeable**	-	-	2	-	3	6	2	-
20	**No understanding of the specific chemical idea tested in the question**	1	-	3	7	1	-	1	-
30	**Understanding of only some aspect/s of the specific chemical ideatested in the question**	13	28	9	20	9	19	3	6
31	Kinetic energy depends on the temperature	8	17	5	11	2	-	1	-
32	Kinetic energy of the gas particles is proportional to the weight/mass and velocity of the particles	1	-	4	9	4	9	2	-
33	Velocity and molecular weight of the particles are inversely proportional with each other	4	9	-	-	3	6	-	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	22	48	21	46	32	68	37	79
41	Relating the kinetic energy only to mass/weight of the particles (The less/more molecular mass the more KE)	12	26	1	-	16	34	1	-
42	Relating the kinetic energy only to velocity of the particles (The faster movement the more kinetic energy)	7	15	3	7	11	23	6	13
43	Relating the kinetic energy to the number of collisions of the particles	1	-	3	7	-	-	11	23
44	Relating the kinetic energy to pressure of the gases in the container	-	-	7	15	1	-	8	17
45	Relating the kinetic energy to the volume of the container	-	-	7	15	-	-	11	23
46	Relating the kinetic energy to the geometric structure of the particles	2	-	-	-	4	8	-	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	3	6	-	-	2	-
51	The more collisions of the particles with the wall of the container the bigger velocity	-	-	3	6	-	-	2	-
60	**Sound understanding of the specific chemical idea tested in the question**	13	28	12	26	9	19	7	15

As shown on Table 4.2, less than 10% of the responses were blank. A few of the responses were uncodeable and showed no understanding of the kinetic energy idea.

More responses showed a partial understanding of the specific chemical idea tested in the question at the pre-test rather than the post-test. The fact that *kinetic energy depends on the temperature* (coded as 31) was seen in 28% (total for **a** and **b**) of the responses in the pre-test while it dropped to 6% in the post-test. *Kinetic energy of the gas particles is proportional to the weight/mass and velocity of the particles* (coded as 32) was observed in 11% percent of the pre and the post-test responses. Less than 10% of the pre and the post-test responses included the idea that *velocity and molecular weight of the particles are inversely proportional to each other* (coded as 33).

There was a noticeable decrease in the partial understandings in the post-test compared to the pre-test. This is most probably because of the fact that kinetic energy was taught at the beginning of the semester close to the pre-test and the students had fresh knowledge about the subject. This is supported by the the proportion of students exhibiting a sound understanding of the subject which was relatively high in the pre-test (28% and 26% respectively for **a** and **b**) compared to the post-test (19% and 15% respectively for **a** and **b**). Students are most likely to recall chemical knowledge during administration of the pre-test.

The converse was true in relation to the misunderstandings in the pre and the post-test. The number of misunderstandings observed in the pre-test (48% and 46% respectively for **a** and **b**) were significantly increased in the post-test (70% and 79% respectively for **a** and **b**). These figures also support the previous evidence that students are more able to answer the question correctly when their knowledge was fresh. However it is important to consider that the proportion of the responses showing misunderstandings was still significantly high which indicates that kinetic energy has not been fully understood.

The highest number of misunderstandings concerned *relating the kinetic energy only to mass/weight of the particles* (coded as 41). This was identified in nearly one third of the the pre and the post-test responses. The misunderstanding which *relates the kinetic energy only to velocity of the particles* (coded as 42) was observed in almost one in four of the pre-test responses and 36% of the post-test responses. Less than 10% of the pre-test responses displayed a misunderstanding in which *kinetic energy related to the number of collisions of the particles* (43) while this was nearly one in four at the post-test. Misunderstandings that *relate the kinetic energy to the pressure of the gases* (coded as 44) and *the volume of the container* (coded as 45) were identified in 15% of the pre-test responses and nearly one in five of the post-test responses. The number of students who misunderstood that *the kinetic energy is related to the geometric structure of the molecules* (coded as 46) was one of the lowest figures amongst the responses.

There were a number of misunderstandings identified in less than 5% of the responses which are reported here without discussion.

- *Relating the kinetic energy to the number of moles of gases (the same number of moles means the same average kinetic energy)*
- *All the gases have the same kinetic energy value*
- *Energy is an extensive property*
- *The less molecular collision the more molecular velocity*
- *Relating the kinetic energy to the magnitude of the particle size (the bigger molecule the bigger/smaller kinetic energy)*

- *The less movement the less energy*

One misunderstanding was identified in general scientific and chemical knowledge (coded as 51), however it occurred infrequently; 6% and less than 5% of responses respectively for the pre and the post-test. In addition, relatively high percentages of the respondents showed sound understanding the tested chemical idea in the question (nearly one in four for the pre-test and 20% of the post-test) compare to potential energy. The misunderstandings which were identified will be discussed in the following section in detail.

4.2.1 Relating the kinetic energy only to mass/weight of the particles (41) (The less/more molecular mass, the more kinetic energy)

This misunderstanding was observed in a very high proportion both in the pre (26%) and post (34%) tests for the sub question a. Since all properties of two gases, He and CO_2, were the same except their molecular mass, students tried to reach the result by comparing their molecular masses as mass is one of the components of the kinetic energy equation, $E_k = ½ m V^2$ and kinetic energy is directly proportional to the mass of the matter. The same equation also shows that kinetic energy is directly proportional to the square of the velocity of the matter. Students related the kinetic energy only with the mass of the matter which produced two different results. These were either the gas which has more molecular mass has higher kinetic energy or the gas which has less molecular mass has higher kinetic energy. Sample quotations are given below to illustrate both cases.

> *The kinetic energy of CO_2 is more. Because kinetic energy is proportional to the mass. The mass of 1 mol of CO_2 is more than 1 mol of He. Therefore its kinetic energy must be bigger than that of He ($OT_1/B/S_{13}$).*
>
> *Here average kinetic energy of helium gas is more than average kinetic energy of carbon dioxide gas. Because their number of moles, volume and temperatures are the*

> *same but since He atoms are lighter than* CO_2 *molecules they can move faster and their kinetic energy becomes more* ($OT_1/B/S_{23}$).

It is clear that students consider mass as the only determining factor for kinetic energy. If they consider that the bigger mass causes higher kinetic energy they choose carbon dioxide. If they perceive the kinetic energy from the faster movement point of view they choose Helium gas.

4.2.2 Relating the kinetic energy only to the velocity of the particles (42) (The faster movement, the more kinetic energy)

This particular misunderstanding was observed at a slightly lower frequency in the pre-test (15% and 7% respectively for **a** and **b**) compared to the post-test (23% and 13% respectively for **a** and **b**). It is also clear that it was more common in sub-question **a** than **b**. In **a**, students mainly focussed on the difference between molecular masses of the gases while in **b** they attributed the kinetic energy difference to the volume of the container. This can be seen in the following extracts.

> Response for sub question **a**: *The kinetic energy of gas molecules is directly proportional to the molecular mass of the gas molecules. Since both of the gases are at the same conditions, average kinetic energy of the gas molecules which has less molecular mass must be more. Here the molecular mass of He gas is less and they will move faster inside the container* ($OT_1/E/S_8$).
>
> Response for sub question **b**: *At container B, because of the small volume of container the number of collision of He gas molecules increase and so their kinetic energy increases* ($OT_1/B/S_{23}$).
>
> Response for sub question **a**: *The average kinetic energy of 1 mol He is more. He is lighter than* CO_2 *molecule and can move faster.* CO_2 *moves slow. The average kinetic energy of He molecules is more, because if a molecule moves faster it has more kinetic energy* ($ST_1/B/S_4$).

The students believed that if a molecule moves faster it must have more kinetic energy but this is only true for the same matter. If the molecules of the same matter move with different velocities those molecules move faster and therefore have more kinetic energy than the others. In that particular question the gases compared are different and therefore comparison is not valid, because average kinetic energy is determined by the mass and square of the velocity. Additionally, students have an idea that if the volume of the container decreases for the same amount of matter at constant temperature the kinetic energy will increase. This is attributed to the increase in the number of collisions which occur and is discussed later.

4.2.3 Relating the kinetic energy to the number of collisions of the particles (43)

Responses for the second part of the question (b) displayed this misunderstanding. Only 7% of the responses included this idea in the pre-test, however it increased to 23% in the post-test. This significant increase may be due to an enhanced approach to problem solving because during the semester students were encouraged to think in more detail about the molecular aspects of chemistry. Some extracts given below show evidence of this.

> *The volume of the second container (Container B) is half of the first one. However both of them contain the same mole amount of He. In the second container because of the small volume of container the number of the collisions of molecules with the wall of the container as well as with each others are much more than that of the first container. Therefore, in the second container kinetic energy will be more (ST_f/B/S_{15}).*
>
> *Since the volume of container B is less than container A, the number of the He molecules per volume in B is more than A. That means there will be more collisions of molecules in container B than A, and this results with more kinetic energy in container B (ST_f/E/S_8).*

This demonstrates that students see the number of collisions between the gas molecules or with the walls of container as a criterion for kinetic energy. In fact the increase in the frequency of collision of gas molecules increases the pressure of the gas which leads to another misunderstanding which is discussed in the next section.

4.2.4 Relating the kinetic energy to pressure of the gases in the container (44)

This misunderstanding was observed in both the pre(15%) and post-tests (17%). Pressure is deemed to be the source of kinetic energy since it increases the number of collisions in container B.

> *The average kinetic energy of the He molecules in container B is more. Because the pressure of He gas is more in that container... (ST$_1$/E/S$_4$).*

There were many similar responses which appeared to be as a result of rote learning of the facts. One of the interviewees' argument at the pre interview also supports questionnaire results.

> *R: What do you know about potential and kinetic energy?*
>
> *I: Kinetic energy is the energy of the particles due to their movement. This can be achieved by mixing [here the word used in Turkish is actually closer to stirring than mixing] the particles. Potential energy should be stationary energy, (pause) I don't know more about it.*
>
> *R: Did you learn this definition in chemistry or physics?*
>
> *I: I knew these definitions from high school. Kinetic energy is movement energy.*
>
> *R: So can you tell me how we can change the kinetic energy?*
>
> *I: By changing the pressure kinetic energy can be changed...(silence).*
>
> *R: Can you give me an example?*
>
> *I: For example, if we put gas particles in a closed container and heat them their kinetic energy increases. This is due to the increase of pressure. By compressing them we can also increase their pressure, because they collide and their energy increases (OI/E/S$_2$).*

The interviewee thought that if molecules were mixed (or stirred,) then their kinetic energy was increased and the pressure also increased as one of the sources of giving the particles a movement. In fact temperature increase is the only factor affecting kinetic energy. Change in pressure or number of collisions are the result of a temperature change.

4.2.5 Relating the kinetic energy to the volume of the container (45)

This misunderstanding occurred with similar percentages to that in 4.2.4. The reasons given were similar and students attributed the source of the kinetic energy only to the volume of the containers and the number of the collisions as demonstrated below.

> *The volume of container B is less than compared to that of container A. Therefore the number of the collisions between the He atoms in container B is more and so they will have more kinetic energy (ST_1/B/S_{13}).*

4.2.6 Relating the kinetic energy to geometric structure of the particles (46)

Whilst this misunderstanding occurred rarely it reveals an important misunderstanding about the kinetic energy of a particle. The students thought that there might be a difference between the kinetic energy of helium and carbon dioxide because of the difference in their geometric structure. Their justification related to the difference in velocities as they thought that if a molecule had a small molecular structure it could move faster compared to a molecule with larger molecular structure.

> *Since the geometric structure of CO_2 is bigger than He their velocities during free movement is less than that of He, thus kinetic energy of He is more than CO_2 (ST_1/E/S_{13}).*

The above misunderstandings stem from considering only one of the factors contributing to kinetic energy. In fact both the mass and the square of the velocity of molecule contribute to the kinetic energy.

4.2.7 The more collisions of the particles with the wall of the container the bigger velocity (51)

This was observed both in the pre-test (13%)and the post-test (6%). Students thought that if the number of collisions increased then the velocity of the particles also increased.

> *When the volume decreases molecules will more often collide with the wall of the container and their velocities will increase...(OT_f/B/S_{18}).*
>
> *... In container B, He molecules (! here respondent did not differentiate atom and molecule concepts as well) will collide to the wall of the container frequently and their velocities will increase. Hence their kinetic energy increases (ST_f/B/S_4).*

If the volume of the same amount of gas reduces at constant temperature the frequency of collisions increases. Its velocity and kinetic energy do not change at constant temperature so the number of collisions does not mean that the particle has more velocity.

4.2.8 Discussion

The responses discussed suggest that chemistry undergraduates experienced difficulty in understanding kinetic energy mostly from two aspects; the molecular mass and the velocity. The equation $E_k = ½ m. V^2$ may lead them into these misunderstandings as many responses start with this equation and further discussion centres on only one of the components of the equation. These results suggest that students, instead of conceptualising the idea behind the equation, simply memorise it as a statement as demonstrated below:

> *R: Could you tell me what is kinetic energy? What do you know about it?*
>
> *I: It depends on velocity and mass. It can be calculated from KE = ½ m V^2 equation.*
>
> ...
>
> *R: Let's say we have two gases, Helium and carbon dioxide, at the same temperature and they are in identical balloons and their volumes are the same, say 1L. How do you compare their average kinetic energy?*
>
> *I: Carbon dioxide has more molecular weight and it is big. Therefore its velocity will be small. Hence it is expected that its average kinetic energy should be less.*
>
> *R: Can you explain your last sentence a bit more please.*
>
> *I: The molecular weight of carbon dioxide is bigger. According to diffusion, the bigger the molecular weight the slower it moves. If the velocity of a particle is small its*

kinetic energy is also small.

R: You approach the average kinetic energy from a molecular weight point of view.

I: Hmm, yes.

R: I remember you gave me the kinetic energy equation few minutes ago, Ek = ½ m V^2, in that equation both mass and velocity contribute the average kinetic energy.

I: But, velocity is square there, I think mass is more important, it determines [the average kinetic energy].

R: How can you compare the average kinetic energies if the gases are the same but their volumes are different. Their temperatures and number of moles are the same as well. Think about helium gas, let say we have two balloons of 1 mole of helium one in 2L and the other is in 1L volume. Their temperatures are the same.

I: If we think the per volume, in that case in the bigger balloon the pressure will be less, emm, pressure can be, emm I think in the bigger volume kinetic energy will be more.

R: Can you tell me why you thought like that?

I: For example, in the bigger balloon the number of gas molecules colliding with the walls of the balloons will be less. Therefore the pressure of the gas will be less. The possibility of collision of the particles with each other is also less. Therefore their velocities change, and emm. That is why its [helium in bigger volume] kinetic energy is low (SI/B/S_3).

In many cases temperature was not mentioned despite the fact that it is the only factor that alters the average kinetic energy of gas molecules. Students thought that anything which affects the velocity of the gas molecules also affects the average kinetic energy. In some cases when they compared the masses of the particles they assumed the velocities of two different gas molecules at the same temperature stayed the same. There was a strong belief that if the velocity of a particle is high then its kinetic energy must be also high. This is only valid if the gas molecules are the same. If there are different kinds of gas molecules this is not true because their molecular masses partly determine the average kinetic energy. A molecule can move more slowly with a heavy molecular mass but still have more kinetic energy than matter which moves rapidly with a very small molecular mass. As a result, it should be emphasised that neither the molecular mass nor the velocity determine the kinetic energy itself but both of them contribute.

Another significant finding was that students' understanding was not consistent and was very fragmentary. It was found that they applied it in one situation but not in another (Stavy, 1988). For instance the same respondent related the kinetic energy to only the different molecular masses of the gases in sub question (a) where the gases are different in both containers, but related the kinetic energy to only the velocity of the particles in sub question (b) where gases were the same in both containers but their volumes were different. These results suggest that teachers and lecturers emphasise more the symbolic level learning, perhaps unintentionally, and problem solving at the expense of the phenomena and molecular level understanding (Gabel, 1993). Therefore students make insufficient connections when they have to apply symbolic level knowledge to a molecular level. This is also supported by Nakleh's (1992) study.

It is well documented that simply telling students that matter is composed of particles and their behaviours are summarised in kinetic molecular theory is not enough. Such scientific laws and statements are easy to memorise but understanding and applying them to phenomena is difficult (Benson *et al*,1993).

Finally there is a noticeable difference between the respondents exhibiting sound understandings of potential energy (around 10%) and kinetic energy (around 25%) even though both of them are fundamental concepts in chemistry at a molecular level. This is clarified in Duit's (1987) study which states that "Whereas potential energy only exists to speak in our thought, kinetic energy is associated more strongly with something observable (p.42)". This is another way of saying that abstract concepts are much more difficult to understand.

4.3 Perfect Gases

Perfect Gases examines internal energy changes of perfect gases at constant temperature. It is an application of potential energy and kinetic energy in a problem. The idea tested is that internal energy is the sum of the kinetic energy of all particles and the potential energy arising from their interactions with one another. The questions and expected answers can be seen in Appendix 8.

Table 4. 3 Analysis of the students' responses to *Perfect Gases*

Code	Description	Pre-test (n=45)		Post-test (n=44)	
		f	%	*f*	%
00	Blank	7	16	4	9
10	Uncodeable	1	-	2	-
20	**No understanding of the specific chemical idea tested in the question**	3	7	9	20
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	20	44	16	36
31	At constant temperature, internal energy of a perfect gas does not change	12	26	8	18
32	Internal energy is a state function	1	-	2	-
33	$\Delta U = q + W$	7	16	3	7
34	Internal energy only changes with q (heat) and W(work)	-	-	3	7
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	16	36	14	32
41	Volume increase decreases the internal energy of a perfect gas	5	11	8	18
42	Internal energy increases if the number of collision of particles increases	3	7	3	7
43	Internal energy increases/decreases by W (expansion work) in the case of isothermal expansion of a perfect gas	3	7	3	7
44	Internal energy decreases because of pressure decrease	4	9	-	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	2	-	-	-

Table 4.3 shows that 16 % of the pre-test and 9% of the post-test responses were blank and that only a small percentage of the responses were uncodeable. There was a fairly high number of responses which displayed no understanding of the specific chemical idea tested in the question at the post-test (20%) whereas this was about 7% in the pre-test.

44% of the responses in the pre-test and 34% of the responses in the post-test demonstrated partial understandings of internal energy. Amongst them the idea that *internal energy of a perfect gas at constant temperature does not change* (coded as 31) occurred at highest percentages, 26% at the pre-test and 18% at the post-test. Few responses included the fact that *internal energy is a state function* (coded as 32). In addition, 16% of the responses in the pre-test and 7% in the post-test included the equation, $\Delta U = q + W$, of internal energy change (coded as 33). Finally, three of the respondents in the post-test explained that *internal energy changes with both heat and work* (coded as 34).

The responses showed similar percentage results at the pre-test (36%) and the post-test (32%). The most common misunderstanding was that *volume increase decreases the internal energy of a perfect gas* (coded as 41) which was found in 11% of the pre-test and 18% of the post-test responses. Both the pre and the post-test (7%) responses included the misunderstanding (coded as 42) that *internal energy increases if the number of collision of particles increases.* The same number of students also had the misunderstanding that *internal energy increases by W (expansion work) in the case of isothermal expansion of a perfect gas* (coded as 43). There was a misunderstanding that *internal energy decreases* *because of pressure decrease* (coded as 44) which was only identified in 9% of the pre-test responses.

There was no evidence for misunderstandings relating to general chemical/scientific knowledge in significant percentages. The results show that there is only a small decrease in the number of misunderstandings in the post-test which indicates that they are persistent throughout the semester. The misunderstandings which were determined will be discussed in the following sections in detail.

Finally, there were misunderstandings that were identified in only one or two of the responses but not displayed in the table. These are given below.

- *Internal energy increases because of increase of entropy*
- *Internal energy is energy of molecules at constant volume*
- *If the possibility of collision of particles decreases the kinetic energy will decrease*
- *Volume increase reduces the rate of movement of molecules at constant temperature*
- *Energy is directly proportional with volume changes*

It is significant that only two responses showed a sound understanding of the specific chemical idea tested in the question (coded as 60).

4.3.1 Volume increase decreases the internal energy of a perfect gas (41)

This was one of the most widespread misunderstanding with11% of the pre-test responses including this misunderstanding and almost double this in the post-test.

The majority of the respondents focussed on the volume change of the gas as it is the only variable that changed in the question.

The misunderstanding that internal energy decreases with increased volume of a perfect gas was argued in two ways. Some of the respondents thought that an increase in volume increases the distance available for a molecule to travel inside the container and this causes the molecules to lose their internal energy due to travelling a great distance. This kind of approach is illustrated in the following response.

> *After the expansion, internal energy of the gas definitely decreases, because, the volume of gas will increase. However, the same number of gas molecules will be inside the container. Each gas molecule has to travel long distances compared to what they do when they are in a small volume. So they spend more energy for this journey and their internal energy will decrease* ($OT_2/E/S_{12}$).

The respondent emphasises that internal energy decreases due to the increase of the distance inside the container in which the gas molecules travel. This type of response firstly suggests that the molecular behaviour of the gases is not well understood. The respondent believes that energy will be used up as gas molecules travel. Secondly, students are not aware of the fact that the internal energy of the perfect gas molecules is the sum of the kinetic energies of the molecules, as the potential energy of a perfect gas is zero (see Potential Energy in Appendix 8 for an extensive discussion) and also at a constant temperature the kinetic energy does not change, hence the internal energy of the system does not change.

On the other hand, internal energy increases if the volume of the sample is expanded isothermally because of the attraction forces between the particles in the case of real gases. However, in this question, the gas in the container is a perfect gas in which there are no interactions between the molecules. The internal energy of a perfect gas is independent of the separation of molecules and hence independent of the volume of the sample occupied (Atkins 1997, p.99).

> *$dU = S.dT - p.dV \rightarrow dU = - p.dV$ (since $dT = 0$ at constant temperature)*
>
> *According to the last equation ($dU = - p.dV$) internal energy is conversely proportional with volume, hence internal energy decreases (ST_2/BS_{13}).*

The second category of responses approached the problem from a more mathematical point of view in which the determination of some physicochemical equations are given. When students use mathematical equations they are more likely to make mistakes because many equations in physical chemistry are derived under certain conditions and with certain assumptions. Memorising the equations without understanding the assumptions often leads to misunderstandings. For instance, in the second quotation above, the equation given was wrong and is actually $dU = S\ dT - P\ dV$. But respondent recalled it as $dU = T\ dS - P\ dV$ in which temperature is an important component leading to a misunderstanding. Even those who gave the correct equation still misinterpreted the equation which resulted in a misunderstanding.

4.3.2 Internal energy increases if the number of collision of particles increases (42)

This misunderstanding was observed in a small number of responses. The underlying misunderstanding was that when the volume increases, the frequency of collisions decreases and this leads to a decrease in the internal energy of the gas as illustrated below.

> *Whereas internal energy of the gas in container A is more, internal energy of the gas in container B is less. Because, the volume of the container doubled, thus the number*

> *of collisions decreased. Since the collisions of the molecules with each others and the wall of the container decreased, internal energy increases ($OT_2/B/S_7$).*

Once again for a perfect gas it is assumed that all collisions are elastic and the total kinetic energy of the colliding particles is the same before and after the collision. Therefore internal energy does not change with an increase in the number of collisions of perfect gas particles.

There was another approach which related the internal energy to the attraction forces because of the collision of the molecules. Respondents related the internal energy to the intermolecular interactions between the particles which is true for a real gas but not for a perfect gas.

> *After the expansion, internal energy decreases. Because the attraction forces between the molecules decreases ($OT_2/E/S_{15}$).*
>
> *...When volume increases the number of collisions between the particles decreases. This decreases internal energy ($OT_2/E/S_3$).*

In these responses students considered the gas as real gas, even though it was stressed in the question that it is an ideal gas, which led to the misunderstanding.

4.3.3 Internal energy increases/decreases by W (expansion work) in the case of isothermal expansion of a perfect gas (43)

This was observed in 7% of the responses both in the pre and the post-tests. This misunderstanding, once again, may originate from the misinterpretation of the internal energy equation, $\Delta U = q + W$. As seen from the equation there are two components of internal energy, heat and work. Students thought that since at constant temperature heat changes are zero, internal energy should only change by work. The system involves an isothermal expansion in which there is no work done by the system since gas is perfect in which there is no interaction between the gas molecules and hence there is no change in the internal energy of the system. Students were confused because they considered that there must be expansion work (P. ΔV). This is illustrated below:

> *Internal energy of the gas increases. Since the volume of container increases, the amount of the work done by the gas increases. Hence internal energy increases because expansion is isothermal in which q stays constant ($ST_2/E/S_3$).*
>
> *Internal energy of the system is equal to q + W at the beginning. At constant temperature there is no heat exchanges and so internal energy change becomes equal to the work done. At the beginning $\Delta U = q - P.V$ (because $W = P.V$). Then the volume of the container isothermally doubled where $\Delta U = - P(2V - V)$, and finally $\Delta U = - P.V$. According to the last equation internal energy will decrease ($ST_2/B/S_{11}$).*

The quotations show that there are two ways of approaching the issue; firstly that work is done on the system during expansion thus increasing the internal energy, and secondly that the system does work during expansion therefore the internal energy of the system decreases. The quotations also show misinterpretations of the equations.

4.3.4 Internal energy decreases because the pressure decreases (44)

This misunderstanding was identified in 9% of the pre-test responses and may be as a result of little understanding of the idea at the beginning of the semester as the quotation below shows:

> *If volume increases pressure will decrease. Internal energy will decrease because the distance between the particles will increase ($OT_2/E/S_2$).*

Another reason for this misunderstanding may be the idea that at low pressures the possibility of collisions of the particles will be lower, therefore the internal energy will be less in the case of the expansion of a gas.

4.3.5 Discussion

The results show that students' knowledge about internal energy at the beginning of semester was limited as well as very fragmentary at the end of the year. It is apparent from many responses that they prefer using mathematical equations to making interpretations at a molecular level. Although nearly half of the responses displayed partial understanding, they also included misunderstandings and only one response showed sound understanding. These overall figures suggest that students' knowledge of internal energy of perfect gases is quite poor. It has been seen in many responses that students did not notice that the question referred to a perfect gas and consequently made misinterpretations. Most of the students who used mathematical equations were not able to deduce correct conclusions from them. They either ignored or misunderstood critical assumptions which must be taken into consideration. Teaching internal energy from a more conceptual point of view which involves insights into molecular level of matter, may help to overcome these kinds of misunderstandings as Waite (1985) suggests.

4.4 Explosion in a Steel Box

Explosion in a Steel Box explores the students' understanding of the internal energy of an isolated system. It includes the application of the first law of thermodynamics in a problem. The tested idea was the internal energy of an isolated system is constant. An explosion had been chosen because many chemical changes occur during the process; some bonds are broken, some new bonds are formed and heat is released. All these aspects represent the transformation of energy from one form to other but the total energy remains unchanged in an isolated system. The question and expected answer can be seen in Appendix 8. Table 4.4 summarises results.

Table 4. 4 Analysis of the students' responses to ***Explosion in a Steel Box***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	**Blank**	10	22	2	-
10	**Uncodeable**	2	-	5	11
20	**No understanding of the specific chemical idea tested in the question**	3	6	4	8
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	14	30	12	26
31	Internal energy is the total energy of a system	1	-	3	6
32	Internal energy is a state function	2	-	2	-
33	$\Delta U = q + W$	6	13	5	11
34	Internal energy of the system does not change	5	11	2	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	30	64	30	64
41	Internal energy increases because of the temperature increase inside the box after the explosion	13	28	15	32
42	Internal energy increases because of pressure increase within the box after the explosion	12	26	8	17
43	Internal energy increases due to entropy increase after the explosion	1	-	4	8
44	Internal energy increases because of increase of kinetic energy of the system after the explosion	1	-	3	6
45	Internal energy of a system is zero if there is no change in temperature and pressure of the system	3	6	-	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	7	15	6	13

As can be seen from Table 4.4 there was a high proportion of blank responses in the pre-test (22%) which significantly dropped to less than 5% in the post-test. This was not unexpected since students knew little about the idea at the beginning of the semester. A few responses were uncodeable. Less than 10% of the responses demonstrated no understanding of the specific chemical idea tested in the question. However nearly one third of the responses, 30% at the pre-test and 26% at the post-test, displayed partial understanding the specific chemical idea tested in the question. These were mainly the facts about internal energy such as that it is; *the total energy of the system* (coded as 31), *or a state function* (coded as 32); and the essential equation of internal energy $\Delta U = q + W$ (coded as 33), which was one of the highest figures among the responses (13% at the pre-test and 11% at the post-test). Finally, 11% of the pre-test responses and only two responses in the post-test stated that *the internal energy of the system does not change (coded as 34).*

This question revealed several misunderstandings present in 64% of the responses. The responses were dominated by two misunderstandings; that *internal energy increases because of the temperature increase* (coded as 41), occurring in 28% of the responses at the pre-test and 32% at the post-test, *and pressure increase* (coded as 42) occurring in 26% of the responses at the pre-test and 17% at the post-test.

Some of the respondents attributed the change to both temperature and pressure while others attributed it to one of these therefore these misunderstandings are considered as separate. A misunderstanding relating to the entropy stated as *internal energy increases due to entropy increase after the explosion* (coded as 43) was identified in one pre-test response and 8% of the post-test responses. Another misunderstanding, *internal energy increases because of increase of kinetic energy of the system after the explosion* (coded as 44), is observed in 8% of the responses in total. Finally, *internal energy of a system is zero if there is no change in temperature and pressure of the system* (coded as 45) was seen only in 6% of the pre-test responses. The misunderstandings which were identified infrequently were:

- *Internal energy changes by q (heat) released after the explosion*
- *Internal energy of an isolated system depends on the temperature/ volume/ pressure or concentration*
- *Internal energy of a system is zero if the system is in equilibrium*
- *The bigger the change in internal energy the faster reaction occurs*
- *In order to make a change in an insulated system internal energy must be constant*
- *Within an insulated system, system variables (temperature, pressure etc.) cannot be changed*

Almost the same number of responses showed sound understanding of the specific chemical idea tested in the question (coded as 60) occurring in 15% of the pre-test and at 13% of the post-test. This misunderstanding will be examined in detail in the following sections.

4.4.1 Internal energy increases because of the temperature increase inside the box after the explosion (41)

This particular misunderstanding was the most common with 28% of the responses in the pre-test and 32% of the responses in the post-test containing it. The reason for the misunderstanding was clearly that the changes inside the system had been considered rather than considering the system as a whole. The temperature increase within the system had been thought of as the source of increase of internal energy because internal energy is changed by heat and work. Respondents thought that the temperature increase meant that heat was transferred to the system causing an increase in the internal energy of the system. There were many responses similar to the one which is given here:

> *Heat is released after the explosion. Since the system does not do work with this*

> *heat, it increases the temperature of the system. Therefore internal energy of the system increases (ST$_1$/B/S$_{13}$).*

This kind of misunderstanding was most probably caused by the incorrect use of mathematical equations.

Students are most likely to confuse heat and temperature. If there is a temperature increase it is common to think that there is an accompanying heat transfer, however, the temperature of a system can be increased in different ways such as doing work on a system. In this question, there is no heat transfer or work on the system since it is insulated from its surroundings. This means that the total internal energy of the system does not change as a result of the explosion.

4.4.2 Internal energy increases because of increase of pressure within the box after the explosion (42)

This was also a common misunderstanding with 26% of the pre-test and 17% of the post-test responses containing it. A few of the responses are quoted below.

> *Pressure has been changed and work has been done against pressure. This increases internal energy (OT1/B/S11).*
>
> *... $W = P.\ \Delta V$. According to this equation, work has been done due to pressure increase. This work increases the internal energy (OT1/B/S20).*
>
> *After the explosion... since temperature and pressure increase there is an increase in the number of particles colliding with the surface of box, hence internal energy increases (OT1/E/S12).*

These responses suggest that students thought that a pressure increase within the box must cause an increase in the internal energy, because a pressure increase results in work being done. Some of them used the equation of work done in the case of expansion, $W = - P\ \Delta V$, but they failed to observe that there is no change in volume of the box; ΔV will be equal to zero, hence the work will be equal to zero. In fact there is no work done by the system, because it is an isolated system and furthermore there is no energy transfer to the system though energy transformations occur within the box such as transformation of bond energies to heat.

4.4.3 Internal energy increases due to entropy increase after the explosion (43)

This misunderstanding was particularly evident at the post-test (11%). Students thought that internal energy increases were due to entropy increases. This is perhaps, again, the result of reliance on mathematical equations, as demonstrated by the following quotations.

> *$dU = T\,dS - P\,dV$.*
> *Entropy increases. Temperature and pressure increase. A decrease in internal energy cannot be considered. $dU = T\,dS$ since V constant. Both entropy and temperature increase, so dU increases ($ST_2/B/S_2$).*
>
> *$dU = T\,dS - P\,dV$. There is an increase in entropy, however volume has not been changed. If entropy increases internal energy increases ($ST_2/B/S_3$).*
>
> *Since there are no free molecules and atoms before the explosion internal energy is small, and after the explosion internal energy increases ($ST_2/E/S_{13}$).*

Whilst the entropy increase is not explicitly mentioned in the last quotation an increase in the entropy of the system is implied. The entropy of some of the parts of the system increases after the explosion (i.e. an exploded bomb). However, in order to increase the internal energy of the system there must be energy transferred either into or out of the system. Since there is no transfer of energy into or out of the system the internal energy does not change.

4.4.4 Internal energy increases because of increase of kinetic energy in the system after the explosion (44)

This misunderstanding indicates an important difficulty in the understanding of internal energy. There may be an increase in the kinetic energy of some components of the system within the box due to the transformation of energy even though the system is isolated. The only way of altering the internal energy is to add energy or lose it from the body. So where there is an increase in the kinetic energy there must be a corresponding decrease in another type of energy to maintain the constant value.

There was another misunderstanding about kinetic energy in the responses. Students thought of kinetic energy and vibrational, rotational and translational energies as different even though kinetic energy is the sum of the vibrational, rotational and translational energies. This is evident in the following quotation:

> *After the explosion internal energy of the system increases, because the total energies of the gases formed after the explosion, kinetic energy plus vibrational, rotational and transnational energies, are increased* (ST_f*/B/*S_{14}).

4.4.5 Internal energy of a system is zero if there is no change in the temperature and pressure of the system (45)

This misunderstanding was observed in 6% of the responses at the pre-test. It explores the fact that students relate the internal energy only to pressure and temperature. If there is a change in temperature and pressure of the system there must be a change in the internal energy of the system, or if temperature and pressure are constant internal energy must be zero. These are shown in the quotations below:

> *... Since temperature and pressure are constant before the explosion internal energy of the system is zero. After the explosion due to temperature and pressure increase internal energy of the system increases* (ST_f*/B/*S_{10}).

> *... before the explosion internal energy of the box is zero but after the explosion internal energy of the box increases in connection to increase of pressure and temperature* (ST_f*/E/*S_{17}).

4.4.6 Discussion

This question revealed that most of the students consider that a temperature and pressure increase within an insulated system causes an increase in its internal energy. In many cases students did not consider the whole system but concentrated on the changes which occurred in a part of the system. Also, they did not take into consideration the changes which happen in the system which cause parallel changes in its surroundings. Students generally have an inclination to use mathematical equations to solve problems resulting with some success in cases but not always.

The results also show that the percentage of misunderstandings in the post-test was considerably higher than in the pre-test responses perhaps because of the fact that the learning process had not been completed yet. In order to complete the learning, students should be able to assimilate the new knowledge by sorting and rearranging their existing knowledge with the new information. The fragmented nature of students' responses appears to indicate that the assimilation of the new knowledge had not been successfully achieved.

4.5 Water

Water investigates the undergraduates' understandings of the fact that the internal energy change of a system is equal to either the heat gained or released in the system or work done by the system or on the system or both of them. That means that the internal energy can be altered by doing work or by heating. The question and expected answer can be seen in Appendix 8. Table 4.5 summarises the results.

Table 4. 5 Analysis of the students' responses to *Water*

Code	Description	Pre-test (n=45)		Post-test (n=44)	
		f	%	*f*	%
00	**Blank**	8	18	6	14
10	**Uncodeable**	-	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	1	-	1	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	22	49	28	64
31	Heating the beaker and its contents cause an increase in the internal energy	12	27	17	39
32	Final internal energy of the both beakers is more than compare to their initial internal energies	9	20	9	20
33	$\Delta U = q + W$	1	-	2	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	13	29	24	55
41	Doing work on the system does not alter the internal energy	7	16	13	30
42	Internal energy only changes with the q (heat) given to the system	2	-	4	9
43	Internal energy of the beaker 1 and its contents does not change	-	-	4	9
44	Heating the system causes more internal energy increase than doing work on the system	3	7	-	-
45	Internal energy change is only equal to the work done on the system	1	-	3	7
46	Internal energies of both beakers do not change	1	-	3	7
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	7	16	4	9

Table 4.5 shows that 18% of the responses at the pre-test and 14% at the post-test were blank, a few responses were uncodeable and a few demonstrated no understanding of the specific chemical idea tested in the question.

There was a high proportion of responses that demonstrated partial understanding the specific chemical idea tested in the question (coded as 30) both in the pre-test (49%) and the post-test (64%). These percentages suggest that students have a fragmented knowledge about internal energy both before and after teaching, because they have been taught some bits of it in the first year in general chemistry courses and also in the second year. Therefore they have only a partial knowledge of the idea before coming to the physical chemistry course. After teaching the number of partial understandings increased. However, there was a considerable increase in the misunderstandings about internal energy after teaching. Before teaching students may be confident in what they know about the idea by relying on their existing knowledge but after teaching because of the lack of assimilation of the new knowledge they may not be as confident as they were. This suggests that not only transmission of the knowledge is required, but also a certain period of time to assimilate.

In this particular question, 29% of the pre-test and 55% of the post-test responses displayed misunderstandings. The reason for the increase may be unassimilated knowledge of the subject or alternatively misunderstanding resulting from new knowledge. Six different misunderstandings were identified. From the table it can be seen that a reasonably high percentage of the students (16% in the pre-test and 30% in the post-test) believed that *doing work on the system does not alter the internal energy* (coded as 41). Some 10% of the students stated that *internal energy only changes with the q (heat) given to the system* (coded as 42). Another 9% of the responses included the misunderstandings that *internal energy of the beaker 1 and its content does not change* (coded as 43) and *heating the system causes more internal energy increase than doing work on the system* (coded as 44). Less than 10% of the responses also included the misunderstanding that *internal energy change is only equal to the work done on the system* (coded as

45). Finally, about 10% of the responses included the notion that internal energy of both beakers does not change (coded as 46). In addition to these common misunderstandings, there are others occurring in only one or two of the responses. These are:

- *Altering thermal equilibrium decreases the internal energy*
- *Internal energy of beaker one and its content decreases*
- *Internal energy increases by increasing entropy*
- *Internal energy is the total kinetic energy of the molecules (This is only true for the perfect gases)*

Slightly more responses in the pre-test (16%) showed sound understanding of the subject of the question (coded as 60) than in the post-test (9%). These results indicate that students can answer more confidently and show more sound understanding when they have a clear understanding of the subject.

4.5.1 Doing work on the system does not alter the internal energy (41)

This was the most common misunderstanding identified. 16 % of the pre-test and 30% of the post-test responses displayed this misunderstanding. Most of the students attributed the change in internal energy of the system only to the heat that is given to the system. There was an obvious increase in the number of misunderstandings in the post-test compared to the pre-test. Some examples are shown below:

> ***...In beaker one internal energy changes because of the heat supplied. Whereas in the second beaker internal energy does not change because there is no volume change and work is zero***
> ***(since $W = P. \Delta V$) ($OT_2/B/S_{24}$).***

Students thought that work can only be done when volume changes. It seems that their understanding is based upon the work being composed of only the expansion work which is done during expansion of a gas against an external pressure. This is most probably due to the examples which have been chosen only from expansion of gases during teaching. Therefore they only consider expansion of a gas as a process in which work has been done.

> *The internal energy of the first beaker increases but the internal energy of the second beaker does not change because we supply heat to the first beaker, however we stir the second beaker. During stirring no heat change occurs and so internal energy does not change* ($OT_2/E/S_{19}$).

The quotation suggests that the respondent holds the view that internal energy only changes with the heat. Also the respondent argues that it has not been possible to transfer energy into a system by doing work which alters the total internal energy of the system. This type of response also suggests that students have a lack of basic understanding of what energy is and how energy transformations occur at a molecular level.

> *... There is no change in the internal energy of the second beaker because stirring only affects the solubility that there is nothing to dissolve here either...*($ST_2/E/S_1$).

> *Since internal energy depends on the heat, internal energy of the first beaker changes. With respect to the second beaker, the internal energy of the water does not change because internal energy does not depend on the rate of the molecules* ($ST_2/E/S_{20}$).

The above quotations show a lack of understanding of internal energy since in both of them the internal energy is related to some physical event. In the first one the respondent tries to establish a connection between internal energy and factors that affect the rate of a reaction and the second one the respondent describes a relationship between kinetics and thermodynamics.

4.5.2 Internal energy changes only with the q (heat) given to the system (42)

This was seen in less than 5% of the pre-test and 9% of the post-test responses. Students thought that since internal energy changes with heat (or sometimes they used "temperature" instead of "heat") the internal energy of the system should be changed in the first beaker only. They ignored the effect of work on internal energy as shown below:

> *Internal energy of the first beaker which is heated increases because internal energy changes by temperature. On the other hand, internal energy of the second beaker does not change because work does not alter the internal energy ($OT_2/E/S_{13}$).*
>
> *Since internal energy depends on the heat, the internal energy of the first beaker increases. In the second beaker the internal energy of the water compared to its initial state does not change because internal energy does not depend on work ($ST_2/E/S_{20}$).*

It is clear from the quotations given above that some of the students believe that internal energy changes only with the heat given to the system.

4.5.3 Internal energy of the beaker 1 and its contents does not change (43)

This was observed in 9% of the responses at the post-test. The quotations given below describe the students' thoughts.

> *The internal energy of the first beaker is expected to increase but since during the heating some of the water molecules evaporate from the beaker, the number of the molecules reduces and therefore total internal energy does not change ($ST_2/B/S_3$).*
>
> *To the first beaker we supply heat (q). System uses this heat for expansion. I mean it does work with this heat. Hence the internal energy does not change ($ST_2/B/S_4$).*

In the first quotation the respondent considered that due to evaporation of the water molecules, the total internal energy would not be changed. Here it has been considered that evaporation requires energy and the energy supplied to the system is used for evaporation. This seems plausible but here the amount of energy used up by evaporated particles should be considered carefully as we do not have any numerical values and we are not able to make a comparison. It is well known that when an object is heated its temperature increases. If the temperature increases, there must be energy transfer to the system which is not immediately transferred to the surroundings, so it increases the internal energy of the system temporarily.

In the second quotation, the respondent believes that the heat supplied is used up as work through expansion. In practice the expansion of a heated liquid is negligible compared to a gas and therefore there is little expansion work, or PV work.

4.5.4 Heating the system causes more internal energy increase than doing work on the system (44)

Even though no numerical value has been given in the question to indicate how much energy is transferred to the system, some students thought that heating must make a more significant change to the internal energy of the system. This misunderstanding is most likely to result from everyday experiences or alternatively may be due to the idea that kinetic energy of the water molecules can only be changed by heating. This is demonstrated in the following quotation.

> *The internal energy change in beaker one is more. Since temperature increases the kinetic energy of the molecules increases more. In the second beaker only a small amount of temperature increase can be observed (this is because of the collision of the molecules). Therefore, in the second beaker we cannot produce an internal energy change which is different from the initial one* ($OT_2/E/S_{12}$)*.*

4.5.4 Internal energy change is only equal to the work done on the system (45)

This misunderstanding was identified in only 7% of the pre-test responses. These students thought that the internal energy can only be changed by doing work on the system. Also there is a sense that the heat supplied to the system would not change the internal energy of the system because the energy transferred as heat will be used up as work on the system and therefore it will not alter the internal energy of the system. This can be seen in the following quotations.

> *Internal energy change is equal to the work done. In the second beaker by stirring we do work on the system. In the first beaker we just heat it. If we don't do work on the system the internal energy change becomes zero. Hence in the first beaker internal energy change is zero. In the second beaker internal energy changes due to the work done ($OT_2/B/S_3$).*

> *To the first beaker we supply heat (q). System uses this heat for expansion. I mean it does work with this heat. Hence the internal energy does not change.*
> *In the second beaker molecules are forced to move by stirring. Their velocities increase. Their kinetic energies increase, and so they do work. Therefore their internal energies increase ($ST_2/B/S_4$).*

This is another example of confusion about the work done by a system or on a system. The respondent thought that if the water is stirred, the molecules do work instead of work being done on the system.

4.5.6 Internal energies of both beaker do not change (46)

There were two approaches to this. The first was that internal energy is a state function and so it is independent of the path followed, as in this response.

> *There is no change in their internal energies because it is a state function and independent of the way the changes are made ($ST_2/B/S_6$).*

Here it is clear that the student does not know what a state function means, and therefore makes a misinterpretation. A state function is a thermodynamic property that depends only on the current state of the system and is independent of the previous history of the system. A state function is a function of the variables that define the current state of the system (Atkins 1995, p.317).

The second approach was due to insufficient knowledge about the internal energy.

> *Internal energy does not change, but their kinetic energies increase with the increased temperature... ($ST_2/E/S_{11}$).*

It is apparent that the student does not appreciate that an increase in kinetic energy also means an increase in the internal energy of the matter.

4.5.7 Discussion

The results described and discussed in the preceding sections show that most of the misunderstandings are centred around heat and work. The most common misunderstanding was '*doing work on a system does not cause a change in the internal energy of a system*'. Most of the students thought that heat is the only way of altering the internal energy of a system and this was reinforced in the interviews.

> *R: Can you tell me how we can change internal energy of a sample of matter? Let say we have a glass of water. What do you do to change the internal energy of the water?*
>
> *I: If I heat it, its internal energy increases.*
>
> *R: Ok, What happens if you stir it with a mixer for a while? Do you think its internal energy changes?*
>
> *I: I don't think so, emm, there is a cup of water and you are stirring it. If you stir it you give a movement to the molecules of the water, but they move all together. If you think at molecular level nothing happens to them. They only change their place, their energy doesn't change I think (SI/E/S$_8$).*

The interviewee believes that work done on the system does not alter the internal energy of the system. This demonstrates that students can understand how heat can change the internal energy relatively easily but they cannot conceptualise how work alters the internal energy. This is perhaps because heat causes an observable change in a system as Erickson et al (1985) stated. When a substance is heated, an immediate observable change may be evident such as an increase in temperature. However if work done on the system such as by stirring a liquid or compressing a gas there is a less observable change in terms of energy transfer. The results also showed that students are likely to use mathematical equations to reach a conclusion. The percentages of students showing partial understanding and misunderstandings increased after teaching. This suggests that students may develop misunderstandings as they go through the learning process if their understanding has not been fully completed.

4.6 Conclusions

The preceding discussions indicate the essential features of students' understanding of potential, kinetic and internal energy both before and after teaching at an advanced level. The data shows significant misunderstandings among chemistry undergraduates and indicates that some students utilise alternative meanings especially for internal energy. The key findings are discussed below.

Misunderstandings about potential energy

The undergraduates' understanding of potential energy, from a chemical point of view, is very weak and several misunderstandings are apparent. The percentages of the responses including misunderstandings are similar both before and after teaching. Teaching also may lead to new misunderstandings in addition to previous ones as some students are resistant to change. The results may indicate that although individual students will bring unique perspectives to learning, there is sufficient common ground among them to identify common alternative frameworks (Driver,1981). Nearly all of the respondents still utilise the physical perspectives of potential energy and the chemical perspective is rarely mentioned. Many are not able to apply their previous knowledge to a new situation leading to a limited and fragmented understanding and restricting the effectiveness of subsequent learning.

Misunderstandings about kinetic energy

Responses about kinetic energy show that chemistry undergraduates mainly relate it to the mass and velocity of the molecules. A considerable proportion of students are not able to interpret and draw conclusions from the equation of kinetic energy, $E_k = ½ m. V^2$. Temperature is occasionally mentioned as a determining factor of kinetic energy and there is a high percentage of responses which display rote learning.

There is a strong belief that if the velocity of a particle is high its kinetic energy must also be high without considering whether the particles are the same or different. There is a feeling that if a particle is small it should have high kinetic energy related to its velocity.

Responses vary within the same context according to the variables given in the question. The same respondents may give one reason for one variable and then a contradictory statement in a subsequent question. This suggests that their knowledge is fragmented as well as incomplete. Students do not pay sufficient attention to use of chemical terminology and often use terms such mass and weight, temperature and heat interchangeably.

Misunderstandings about internal energy

Responses to the three questions concerning internal energy provided several misunderstandings. The interviews demonstrated that the majority of the students were able to define internal energy but were less able to explain precisely what energies were involved. The results suggest that the students do not understand ideas fully and that they memorise definitions without a deeper understanding of the idea. This perspective can be seen in the below discussion:

> *R: Could we start from internal energy? I just want you tell me what you know about internal energy. Just imagine that you are questioning yourself what you knew about internal energy. What I am asking you is to do just think aloud for me please.*
>
> *I: Internal energy is the total energy of the matter.*
>
> *R: Can you tell me a little bit more about it? For example what do you mean by saying total energy?*
>
> *I: Total energy, for example, there are bonds between the molecules [intermolecular bonds] and also there are bonds in the molecules [intra molecular bonds]. I mean total energy as the energy that is required to break all of those bonds (OI/E/S_{10}).*

The interview results also show that almost all of the interviewees were able to state that internal energy is a state property and that its value depends only on the current state of the system not how the system was prepared.

It is apparent from the responses that students develop new misunderstandings after being taught. They also revealed more partial understandings in the post-test suggesting that there may be some problems in the teaching process, as well as in the students' conceptualisation of the new ideas. Perhaps one of the most important reasons for the misunderstandings is an inadequate level of existing knowledge held prior to learning new ideas. Students' responses to the questions on potential and kinetic energy support this.

Respondents tend to focus on only one aspect of the problems and do not examine the question as a whole resulting in a considerable proportion of the misunderstandings. They also appeared not to be able to differentiate a system and its surroundings.

Students have an inclination to use mathematical equations to solve the problems and avoid attempting to make discussion at a molecular level. They are often not able to correctly interpret a mathematical equation due to rote learning. Students are often aware that they are to be assessed through solving mathematical problems, leading them to memorise rather than understand. Lecturers prefer mathematical problems to those which explore the students' understanding because it is easier to evaluate and mark the responses as they are under the pressure of teaching too many classes and more hours.

Chapter 5

Chapter 5

Analysis of The Responses About *Enthalpy and Related Ideas*

The previous chapter reported the students' responses concerning internal energy and related ideas. In this chapter, the students' responses to five questions about enthalpy and related ideas will be examined. These are: *Copper (II) Sulphate*, *Energy*, *Magnesium*, *Two hypothetical Reactions* and *Ice Melting*. Each question will be discussed separately.

5.1 Copper (II) Sulphate

Copper (II) Sulphate (see Appendix 8) examines the students' understandings of lattice enthalpy, hydration enthalpy and solution enthalpy. It also examines the students' ability to predict types of reaction by looking at an energy level diagram and tests both recall and understanding.

Two sub-questions (**a** and **b**) examine the students' ability to recall essential definitions including lattice, hydration and solution enthalpies. Sub-question (**c**) examines the energy level diagram of an exothermic reaction. Students should be able to understand whether a chemical reaction is exothermic or endothermic by looking at the energy level diagram. One aspect which needs to be clarified about the definition of lattice enthalpy in textbooks is that it is defined in two ways. The first definition is *the energy change when one mole of a crystal is formed from its component ions in the gaseous state* (Matthews 1996, p.263). According to this and other similar definitions all lattice enthalpies are negative. The second definition is the opposite of the first definition stating that *the lattice enthalpy is the* *standard change in enthalpy when a solid substance is converted to a vapour, as in the process* $MX_{(s)} \rightarrow M^{+}_{(g)} + X^{-}_{(g)}$ *for an ionic solid or* $A_{(s)} \rightarrow A_{(g)}$ *for a molecular covalent solid* (Atkins1995, p.199). According to this definition all lattice enthalpies are positive. IUPAC also accepts the second definition of lattice enthalpy (Lide 1999, 12-22). Whichever is used, the only difference is the sign of the lattice enthalpy. For this question, however, as it only tests the recall of a convention, responses showing ΔH_1 as lattice enthalpy are acceptable. The answers are coded and the results are separately tabulated for each sub question, because they assess the different aspects of enthalpy idea.

5.1.1 Copper (II) Sulphate - a

This question only tests the students' ability to recall their understanding of lattice enthalpy and hydration enthalpy. The results are given in Table 5. 1.1.

As shown in Table 5.1.1, one third of the responses in the pre-test were blank whereas this dropped approximately to 10% in the post-test. Also, nearly 15 % of the responses in both the pre and post-tests demonstrated no understanding of the specific chemical idea tested in the question. Responses which included the definition of the process, without giving a proper name to the process, were considered to show partial understanding. The percentages were slightly higher in the pre-test (less than 10%) than in the post-test (only one response). Students were unable to remember the name for the process but in

some cases they defined the process correctly, as illustrated in the following quotation:

> *For* ΔH_1 *: The energy which is given out when gaseous ions form a crystal solid.*

For ΔH_2: The energy which is given out when gaseous ions are hydrated ($OT_f/B/S_{17}$).

Table 5. 1.1 Analysis of the students' responses to ***Copper (II) Sulphate - a***

Code	Description	Pre-test (n=46)				Post-test(n=47)			
		ΔH_1		ΔH_2		ΔH_1		ΔH_2	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	15	33	17	37	6	13	5	11
10	**Uncodeable**	-	-	-	-	-	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	7	15	7	15	6	13	7	15
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	1	-	4	9	-	-	1	-
31	No name given but process has been defined correctly	1	-	4	9	-	-	1	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	20	43	18	39	29	62	27	57
41	Sublimation enthalpy	6	13	1	-	9	19	-	-
42	Formation enthalpy	8	17	1	-	15	32	1	-
43	Solution / dissociation enthalpy	-	-	7	15	1	-	17	36
44	Activation energy	4	9	3	7	1	-	-	-
45	Condensation / liquidation enthalpy	1	-	4	9	-	-	2	-
46	Boiling / vaporisation enthalpy	1	-	-	-	1	-	2	-
47	Freezing / melting enthalpy	-	-	1	-	1	-	1	-
48	Ionisation energy	-	-	2	-	1	-	4	9
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	3	7	-	-	5	11	7	15

With respect to inaccurate recall of the name of the enthalpy changes, a considerably higher number of students failed to remember the name of the enthalpy changes in the post-test (around 60%) than in the pre-test (around 40%). In the post-test more respondents attempted to give an answer to the question than in the pre-test. This offers an explanation for the increase in the number of responses which show an inaccurate recall of the name of the enthalpy changes which accompany the process.

Most of the responses focussed on the sublimation (13% in the pre-test and 19% in the post-test), formation (17% in the pre-test and 32% in the post-test) and activation enthalpy (9% in the pre-test) for ΔH_1. For ΔH_2, responses mainly focussed on the solution/disassociation (15% in the pre-test and 36% in the post-test), activation (7% in the pre-test), condensation/liquidation (9% in the pre-test) and ionisation enthalpy (9% in the post-test).

Students were unable to recognise the lattice enthalpy, especially in the pre-test stage where only 7% of the students showed sound understanding the chemical idea tested in the question and this increased to 11% in the post-test. The results were similar for hydration enthalpy. No one was able to remember the name for the process of hydration in the pre-test whereas 7% recognised it in the post-test. Some of the respondents also referred to the processes of freezing, melting, boiling and vaporisation. These figures indicate that students were unable to recognise the name of enthalpy changes for certain processes. Carson and Watson (1999) report a similar finding that students were unable to define enthalpy change. This might be the result of a straight memorisation of the definition.

5.1.2 Copper (II) Sulphate - b

In this section, the question tests the students' ability to draw an arrow on the energy level diagram which indicates the enthalpy change of the solution. The results are given in Table 5.1.2.

Table 5. 1.2 Analysis of the students' responses to ***Copper (II) Sulphate - b***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	**Blank**	11	24	5	11
10	**Uncodeable**	-	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	3	6	2	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	-	-	-	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	18	39	14	30
41	Drawing a double headed arrow (up and down)	9	20	11	23
42	Drawing a wrong headed arrow	5	11	2	-
43	Drawing a curve which shows the activated complex	2	-	1	-
44	Indicating ΔH_2 as $\Delta_{soln}H$	2	-	-	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	15	33	26	55

Table 5.1.2 shows that 24% of the respondents in the pre-test and 11 % in the post-test left the question blank. Also, few of the responses were uncodeable or demonstrated no understanding and no response indicated partial understanding. The misrepresentation of the hydration enthalpy by drawing a vertical double headed arrow between the two horizontal lines which indicate reactants and products (see the diagram in Appendix 8) was seen in 20% of the pre-test and 23% of the post-test responses. Some 11% of the respondents in the pre-test drew a vertical arrow in the correct place but the head of the arrow was pointing the wrong direction. A few of the responses drew a curve which resembles the curve belonging to the activated complex. Also some of them indicated ΔH_2 as ΔH_{soln} (less than 5% in the pre-test). The percentage of the respondents who showed a sound understanding of the specific chemical idea tested in the question

was 55% in the post-test and 33% int the pre-test. More than half of the students placed a correct arrow on the diagram to indicate the solution enthalpy. However, there were some inconsistencies and some students placed a correct arrow on the diagram to indicate the solution enthalpy but named ΔH_2 as solution enthalpy. These respondents defined two different processes as the same which may indicate memorising diverse pieces of information (Hudson 1994, p.94).

5.1.3 Copper (II) Sulphate - c

This part of the question tests the students' capability in interpreting an energy level diagram. The results are summarised in Table 5.1.3.

Table 5. 1.3 Analysis of the students' responses to ***Copper (II) Sulphate - c***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	**Blank**	12	26	10	21
10	**Uncodeable**	-	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	-	-	-	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	11	24	17	36
31	The temperature of water will rise	8	17	14	30
32	The reaction is exothermic	3	6	3	6
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	25	54	14	30
41	The temperature of water will fall	16	35	4	9
42	The reaction is endothermic	7	15	2	-
43	Dissolution process is always exothermic/endothermic	1	-	5	11
44	The temperature change is related to the entropy changes of the system	1	-	3	6
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	8	17	17	36

Almost one quarter of the respondents in the pre-test and one fifth of the respondents in the post-test left the question blank. There were no responses which were uncodeable or demonstrated no understanding of the specific chemical idea tested in the question.

The number of responses which showed understanding of the some aspect/s of the specific chemical idea tested in the question increased from 24% in the pre-test to 36% in the post-test. 17% of the pre-test and 30% of the post-test responses included the correct interpretation that *the temperature of water will increase* (coded as 31). The second fact, that *the reaction is exothermic* (coded as 32), was identified in 6% of both the pre and the post-test responses. A higher number of students were able to make a correct interpretation in the post-test than in the pre-test as a result of teaching throughout the year.

The number of responses that included some common misunderstandings dropped from 54% in the pre-test 30% in the post-test. Four misunderstandings were identified from the students' writings. These were *the temperature of water will fall* (coded as 41) identified in 35% of the pre-test responses and only in 9% of the post-test responses. *The reaction is endothermic* (coded as 42) was detected in 15% of the pre-test responses. The misunderstanding that *dissolution process is always exothermic or endothermic* (coded as 43) was diagnosed in 11% of the post-test responses. Some of the students *related the temperature changes to the entropy changes of the system* (coded as 44) identified in 6% of the post-test responses. In addition to these misunderstandings one of the respondents argued that bond breaking is an exothermic process. The number of the students who demonstrated sound understanding of the specific chemical idea tested in the question also increased from 17% in the pre-test to 36% in the post-test. In the following sections the misunderstandings which were detected will be discussed in more detail.

5.1.3.1 The temperature of water will fall (41)

This misunderstanding was mostly identified in the pre-test with 35% of the responses containing it. This dropped to 9% in the post-test showing a significant improvement. The responses indicated that students were unable to decide by looking at the energy level diagram whether the reaction was exothermic or endothermic. It also shows that many of the students get the required knowledge from the teaching. Students gave various reasons for their answers, some of which showed an inability to recognise the reaction enthalpy and determine whether the reaction was exothermic or endothermic, by looking at the direction of the arrows. A typical example is:

> *It should fall because, the heat required to dissolve $CuSO_{4(k)}$ will be supplied by the water. Also from the diagram it is clear that ΔH for the reaction is positive. That means that the reaction is endothermic ($OT_1/B/S_2$).*

In an another similar response, a respondent argued that the reaction was endothermic and endothermic reactions require heat from the surroundings. Since it must get the heat from the water, the temperature of the water must have fallen.

> $\Delta H_{reaction} = \Delta H_{products} - \Delta H_{reactants}$
> *If we look to the enthalpy changes of the products, it is bigger than the enthalpy change of reactants. Since $\Delta H_2 \rangle \Delta H_1$ the enthalpy change of the reaction must be positive. That means that the reaction is endothermic. Endothermic system requires heat from the surroundings. Thus the temperature of water falls ($OT_1/B/S_3$)*

Some of the respondents considered only one stage of the reaction and therefore they attributed temperature fall to the disassociation of the copper (II) sulphate in water. In the quotation below the respondent argues that the temperature will fall because the surrounding water supplies the heat required for the disassociation of the solid $CuSO_4$. However they do not consider other changes in the reaction such as the heat given out after the hydration of the ions in the water.

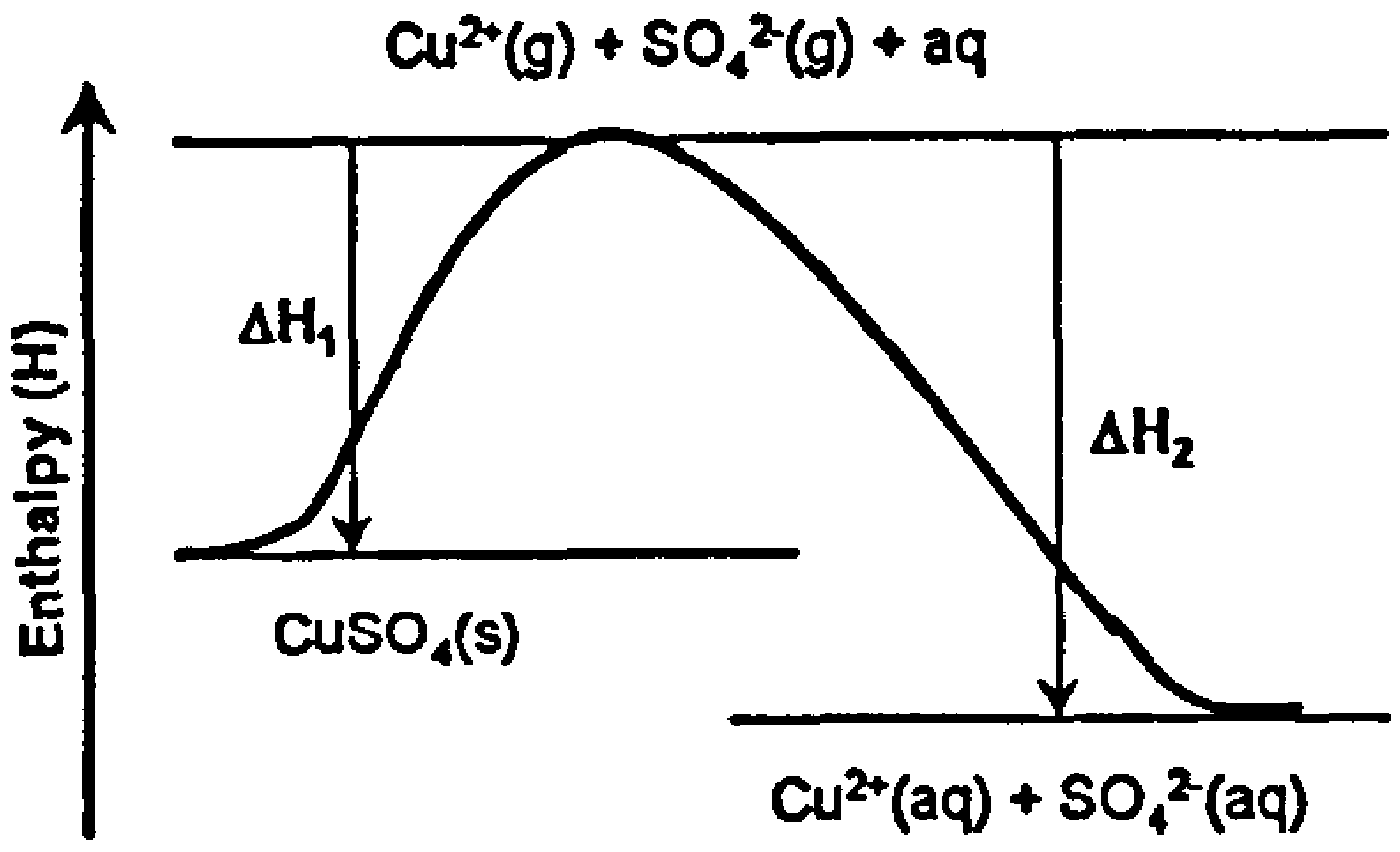
> *When anhydrous copper (II) sulphate dissolves in the water, I expect the temperature of the water to fall because the heat in the water will be used up to break the bonds in the molecule... Thus the temperature of the water compared to the its initial temperature will fall* ($OT_1/E/S_1$).

This quotation is typical of many in that it shows that the determination of the reaction enthalpy change is unclear in the students' minds, even if they had been taught it a number of times prior to coming to physical chemistry. Some of them still cannot determine the type of reaction by looking at an energy level diagram. Also, some of them cannot recognise whether a reaction is exothermic or endothermic by looking the direction of arrows on the energy level diagrams. In fact, interpretation of the energy level diagrams is not a subject of the physical chemistry course content. It is assumed that these basic ideas were already understood. However, the results suggest that this is not the case.

5.1.3.2 The reaction is endothermic (42)

Some 15% of the pre-test and a lesser number of the post-test responses included this misunderstanding. Some of the students believed that the reaction was endothermic and they only looked for the magnitude of the enthalpy changes or the length of the arrows rather than the sign of the enthalpy changes or the direction of the arrows. This led them to misunderstand or misdefine the process.

Another reason may be the drawing style of the energy level diagram where students might have not been familiar with the use of arrows and horizontal lines because some students drew an energy level diagram consisting of a two tailed conical curve where one end of the tail is at a lower level than the other as shown below:



Some typical responses quoted below to illustrate the misunderstanding.

...according to the diagram, the reaction enthalpy is endothermic...($OT_1/B/S_{12}$).

It is clear from the graph that the reaction is endothermic. Thus...($OT_1/E/S_{12}$)

5.1.3.3 Dissolution process is always exothermic / endothermic (43)

This misunderstanding was identified mainly in the post-test responses (11%). The respondents argued that the dissolution process of the solids is always exothermic or endothermic. It is not possible to make this generalisation as dissolution of some salts is endothermic such as KNO_3 or NH_4NO_3. However, when some salts dissolve they generate heat and the process is exothermic such as $CaCl_2$ and $CuSO_4$. Students made a generalisation by relying on only one case as shown below:

...Because the dissolving process is always endothermic ($OT_1/B/S_{18}$).

The dissolution of the solid is always exothermic ($ST_1/B/S_3$).

$CuSO_4$ is a salt. All salts give out heat when they dissolve in water ($ST_1/E/S_5$)

This misunderstanding might be the result of considering the dissolving process as consisting the breaking of the intra molecular bonds which requires energy from the water. Subsequently the ions are hydrated by the individual water molecules and this process is exothermic. Consequently all of the stages should be considered together.

5.1.3.4 The temperature change is related to the entropy changes of the system (44)

This was a rare misunderstanding which was observed in 6% of the post-test responses and only one response in the pre-test. Students tried to find a bridge between the entropy changes of the system and temperature changes of the water. Some typical responses are quoted below:

> *The temperature of the water will rise because the disorder of the system increases, so the entropy (OT_f/B/S_8).*
>
> *The temperature of the water should increase... because when gas molecules get into the liquid phase their entropy will decrease, so the entropy of the system because they will be less disordered in the liquid phase. Entropy and temperature are inversely proportional. Therefore the temperature must increase (ST_f/B/S_5).*

5.1.4 Discussion

Enthalpy is one of the fundamental ideas in chemistry and the responses suggest that it is poorly understood by the undergraduates despite the fact that students are taught it several times at different stages. Around 15 % of the students were able to recall the correct name of the enthalpy changes indicated on an energy level diagram but more than two thirds of the students were unable to recognise and indicate an enthalpy change on an energy level diagram. Carson and Watson (1999) reported similar findings by emphasising that students' explanations of the meaning of enthalpy change lacked precision and discrimination.

From the interviews, it was apparent that many students could not define the enthalpy changes on an energy level diagram. They were asked to define enthalpy changes for various processes such as ionisation, formation and hydration but none of them could give the correct definitions for these processes as illustrated in the below discussion.

> *R: Can you define the ionisation energy?*
>
> *I: Energy required for ionisation, this is the first thing that came to my mind. It is the energy that is required to detach one electron from an atom (SI/B/S_6).*
>
> *R: Can you define the hydration enthalpy?*
>
> *I: It is defined for water, for water...I don't know (SI/B/S_4).*

Moreover, sub question (c) revealed that more than one fifth of the respondents were unable to determine whether the reaction was exothermic or endothermic from an energy level diagram. The results indicate that understanding of enthalpy is poor even at very basic level and that students are able to memorise the facts but cannot apply them to the problems they come across. In addition, students' knowledge is fragmented. They have snippets of knowledge about enthalpy change and dissolution but are not able to apply this knowledge. This could be the result of rather formal teacher-centred teaching. These chunks of knowledge require a very low use of intellectual or cognitive skills (Hudson 1995). Therefore, students should be taught in a more student-centred learning approach so that they can get the help they need to establish the links between the different ideas.

5.2 Energy

Energy tests one of the most widely confused ideas about the sources of the energy generated or used in a chemical reaction and the question was designed both for exothermic and endothermic reactions to a get broad range of responses. The question (see Appendix 8) probes the idea that the enthalpy change of a reaction depends on the overall strengths of the bonds of molecules and/or compounds of the reactants and the products. Table 5.2 summarises the results.

Table 5.2 Analysis of the students' responses to *Energy*

Code	Description	Pre-test (n=46)				Post-test(n=47)			
		a		b		a		b	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	11	24	20	44	8	17	13	28
10	**Uncodeable**	5	11	2	-	2	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	2	-	6	13	2	-	5	11
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	8	17	11	24	17	36	10	21
31	Bond breaking requires energy	-	-	3	6	4	9	-	-
32	Bond making releases energy	1	-	-	-	4	9	-	-
33	It is an exothermic reaction	5	11	-	-	5	11	-	-
34	It is an endothermic reaction	-	-	4	9	-	-	3	6
35	Activation energy is required to start the reaction	-	-	1	-	-	-	7	15
36	Product is more stable than reactants	2	-	-	-	4	9	-	-
37	Reactants are more stable than product	-	-	3	6	-	-	-	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	17	37	8	17	10	21	4	9
41	Bond making requires energy	5	11	5	11	2	-	3	6
42	Bond breaking releases energy	6	13	-	-	1	-	-	-
43	Endothermic reactions cannot be spontaneous	-	-	3	6	-	-	1	-
44	Formation enthalpy is always exothermic	3	6	-	-	2	-	-	-
45	A spontaneous reaction is always exothermic	1	-	-	-	3	6	-	-
46	Products have maximum disorder	3	6	-	-	2	-	-	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	3	6	-	-	-	-	-	-
51	All combustion reactions produce H_2O	3	6	-	-	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	5	11	1	-	10	21	11	23

It can be seen from Table 5.2 that almost one quarter of the responses for part (a) in the pre-test were blank and that this decreased to 17% in the post-test. Slightly less than half of the pre-test responses for part (**b**) were blank in the pre-test and 28% in the post-test. In addition, a few responses were uncodeable. Moreover, over 10% of the pre and the post-test responses for part (**b**) showed no understanding of the specific chemical idea tested in the question.

Many responses showed partial understandings, 17% of the pre-test and 36% of the post-test responses for part (**a**) and 24% of the pre-test and 21% of the post-test responses for part (**b**). Partial understandings were grouped as *bond breaking requires energy* (coded as 31) and *bond making releases energy* (coded as 32). Some of the respondents also indicated the type of reaction by saying *it is an exothermic reaction* (coded as 33) or *it is an endothermic reaction* (coded as 34). Among the partial understandings the fact that *activation energy is required to start the reaction* (coded as 35) for sub question (**b**) was frequent. The rest of the partial understandings were the ideas that *product is more stable than reactants* (coded as 36) for part (**a**), and *reactants are more stable than product* (coded as 37) for part (**b**). If the partial understandings are examined closely it becomes apparent that students are approaching the problem from three perspectives; the first one is '*bond making and breaking*', the second is '*the reaction exothermicity and endothermicity*', and finally '*the stability of products and reactants*'.

In general the results showed some improvement in terms of the number of the misunderstandings from the pre-test to the post-test. As shown in Table 5.2, 37% of the pre-test responses included misunderstandings for part (**a**) but this dropped to 21% for the post-test. Table 5.2 also shows that the number of misunderstandings halved in the post-test for part (b). The small number of misunderstandings for part (b) compared to (a) can be attributed to the low response rate, because only a small number of students answered this part of the question. In fact, almost 60% of the respondents either left sub question (b) blank or the answer demonstrated no understanding of the specific chemical idea tested in the question. As the number of the responses drops, the possibility of revealing misunderstandings correspondingly drops.

The most common misunderstandings were *bond making requires energy* (coded as 41) and *bond breaking releases energy* (coded as 42). Other common misunderstandings were that *endothermic reaction cannot be spontaneous* (coded as 43) and the misunderstanding that *a spontaneous reaction is always exothermic* (coded as 45). Some of the students argued that *formation enthalpy is always exothermic* (coded as 44). Finally some approached the problem from the disorder point of view by arguing that *products have maximum disorder* (coded as 46). Also a few of the responses included a misunderstanding relating to general chemical knowledge, that *all combustion reactions produce* H_2O (coded as 51).

There were numerous misunderstandings which occurred infrequently and these are summarised below:

- *The standard formation enthalpies of elements are bigger than those of compounds.*
- H_2 *and* O_2 *are unstable when they are free.*

- *H-bonds are formed and they cause an energy release (for part (a) only).*
- *Relating the enthalpy changes to the total number of the bonds in the molecules or compounds.*
- *Two gas molecules have more total kinetic energy than one gas molecule.*
- *Mass of the material turns to energy.*

Finally, it should be noted that number of the responses that showed sound understanding of the specific chemical idea tested in the question (coded as 60) improved from the pre-test to the post-test. The percentages of sound understandings for part(**a**) were 11% in the pre-test and 21% in the post-test. Only one response showed sound understanding in the pre-test for part (**b**) and it is significantly increased to 23% in the post-test. The misunderstandings will now be examined in detail.

5.2.1 Bond making requires energy (41) and bond breaking releases energy (42)

These two misunderstandings will be discussed together. They are well known from studies on students' understanding of chemical bonding (Boo 1998, Barker 1995 and Ross 1993). Barker reports that 19% of A-level students hold these misunderstandings. The misunderstanding (coded as 41) was observed at relatively high percentages in the pre-test (11% for both parts (**a**) and (**b**)) compared to the post-test (less than 5% for part (**a**) and 6% for part (**b**)). The second misunderstanding (coded as 42) was only observed in the responses for part (**a**), with 13% in the pre-test and in less than 5% of the post-test responses. It is also important to note that the misunderstandings have a tendency to reduce towards the end of the year. Some typical quotations from the responses are given below:

> *Chemical bonds are broken and form during a chemical reaction. Bond breaking releases energy, and bond making requires energy... (OT_1/E/S_{17}).*
>
> *The energy given out when the bond between H-H breaks and the bonds in O_2 molecules break is bigger than the energy required for the formation of H_2O molecules...(OT_1/B/S_{11}).*
>
> *In this reaction since the bonds are broken in H_2 and O_2 molecules, some energy is given out...(OT_1/E/S_7).*
>
> *In this reaction, it is easier to break the bonds in H_2 and O_2 therefore they give out more energy than the energy has taken to form H_2O...(ST_1/B/S_4).*

It is clear that these misunderstandings are still resistant to change at university. A considerable number of respondents hold them. They are also observed in the pre-interviews but not in post-interviews. The following discussion was taken from a pre-interview.

> *R: Would you tell me have you ever thought that why some reactions are exothermic while some of them are endothermic? Where might this difference arise? or what might it be?*
>
> *I: Some reactions involve bond formation and some involve bond breaking. Bond formation requires energy. If a bond breaks it releases energy.*
>
> *R: You think that bond breaking releases energy, and bond making requires energy?*
>
> *I: Yes...*
>
> *R: How do you know that?*
>
> *I: We learned this (OI/E/S_3).*

This misunderstanding might be due to the strong associations between fuels and energy, which Ross (1993) believes prevent learning the accepted chemists' view. Students believe that molecules are the energy store and when the bonds are broken and molecules are destroyed this energy is released. In reality, when a new molecule or compound is formed it gains energy and stores it within. Ross (1993) and Barker (1995) attribute students' difficulties to the way that fuels are described as energy stores during teaching. In addition, Boo (1998) argues that a large number of students see the chemical bond as a physical entity and students link the everyday notion that building any structure requires energy input and its converse destruction releases energy. This kind of thinking may form the basis for the misunderstanding that bond breaking releases energy and bond making requires energy.

5.2.2 Endothermic reactions cannot be spontaneous (43)

This is also a well documented misunderstanding from previous studies (Johnstone *et al* 1977, Thomas 1997). It only appeared in the responses to part (b) in 6% of the pre-test responses and only in one post-test response. It was infrequent but important to mention here, because it is an important fact that endothermic reactions can be spontaneous. There are examples in everyday life such as vaporisation of water at every temperature. This is an endothermic reaction but it occurs spontaneously. It is also important to note that enthalpy is not the only driving force in a chemical reaction; entropy should also be considered since the Gibbs energy determines whether a reaction can be spontaneous or not at constant temperature and pressure. The following responses illustrate the misunderstanding:

> *This is an endothermic reaction. This reaction cannot occur spontaneously. Therefore energy should be supplied from the surroundings to help the reaction happen (OT$_1$/B/S$_5$).*

The interview results also support data from the questionnaire:

> *R: Can you tell me does reaction exothermicity and endothermicity have an effect on spontaneous occurrence of a reaction?*
>
> *I: If a reaction occurs spontaneously it gives out energy. I mean it is an exothermic reaction.*
>
> *R: OK*

I: Endothermic reactions need energy. Therefore they cannot occur spontaneously (OI/B/S$_{10}$).

This misunderstanding was also observed by Johnstone *et al* (1977) in high school students. According to the research one in six pupils had this misunderstanding. Thomas (1997) also reported that 75% of the fourth year chemistry undergraduates had this misunderstanding which may originate from notion that in spontaneous changes there is a tendency to minimise the energy as Johnstone *et al* (1977) argue. As endothermic reactions are accompanied by an energy intake, students may consider that there is an energy increase and thus this cannot be spontaneous. In addition, students have generally been given an exothermic reaction as an example in their courses, since spontaneous endothermic reactions are rare, which may be another possible cause of the misunderstanding.

5.2.3 Formation enthalpy is always exothermic (44)

This particular misunderstanding was observed in the responses given to the sub question (**a**) and was included in 6% of the pre-test and less than 5% of the post-test responses. It is assumed that students concluded this from the exothermic reaction given as an example because it is a formation reaction of water. However, the second reaction was also a formation reaction but students did not mention the same misunderstanding there. Some typical responses are quoted below:

When two or more atoms are gathered together to form a molecule it generates heat. This heat is formation enthalpy at the same time...(OT$_f$/B/S$_{12}$)

...the formation enthalpy of elements is zero. Here in this reaction the heat that comes out actually belongs to the formation of water. Formation enthalpies are always exothermic...(ST$_f$/B/S$_{22}$)

Students clearly stated the misunderstanding which may originate from the fact that most of the formation reactions are exothermic and the number of endothermic formation reactions is relatively low compared to exothermic formation reactions. This misunderstanding may also stem from students' habits of handling the question only in the available circumstances instead of handling it in a wider perspective. Students did not state the same misunderstanding in part (b) even though it was the formation reaction of NO_2.

5.2.4 A spontaneous reaction is always exothermic (45)

This misunderstanding was also diagnosed in the responses which were given to part (a) by 6% in the post-test and in only one case in the pre-test. This is similar to the misunderstanding that endothermic reactions cannot be spontaneous (coded as 43 and discussed above). Some quotations given below exemplify the case.

> *This reaction can occur spontaneously, therefore it releases energy... (OT_1/B/S_{25})*
>
> *The reaction happens spontaneously, thus it gives out energy. (ST_1/B/S_{10})*
>
> *This is an exothermic reaction. Exothermic reactions occur spontaneously. If a reaction occurs spontaneously it gives out heat. Therefore, there is an energy release after the reaction (ST_1/B/S_{22})*

In the third quotation, the respondent explores the fact that exothermic reactions occur spontaneously. This is true, but the reverse is not always true as some endothermic reactions proceed spontaneously, as explained in section 5.2.2. Students are most likely to get this misunderstanding from the perspective that if an exothermic reaction occurs spontaneously, conversely all the spontaneous reactions should be exothermic.

5.2.5 Products have maximum disorder (46)

Some of the responses given to part (a) included this misunderstanding in 6% of cases in the pre-test and in less than 5% in the post-test. This is a misunderstanding relating to the entropy change of the reaction. Some typical responses are quoted below:

> *In this reaction, the enthalpy of $H_2O_{(g)}$ is less than that of $H_{2(g)}$ and $O_{2(g)}$... In this case, $H_2O_{(g)}$ molecules are more stable than $H_{2(g)}$ and $O_{2(g)}$. Chemical reactions tend to proceed towards maximum disorder and minimum energy. Since the products have the less enthalpy they also must have the maximum disorder ($OT_1/B/S_2$).*

It is apparent from the quotation that the respondent approached the problem from a maximum entropy and minimum energy point of view. In fact, in the reaction, the entropy of the reactants is more than that of the products, because the number of reactants is greater than that of the products. There are two molecules on the left hand side of the chemical equation whereas there is only one molecule on the right hand side of the chemical equation. In this case the determinant of the entropy is the number of the molecules therefore the more molecules the higher the entropy.

> *In this reaction, reactants are in gaseous state. They must have the maximum entropy but H_2O is a single structure, thus its entropy value can be bigger than reactants. Finally because of its (implies H_2O) entropy energy is given out ($OT_1/B/S_8$)*

In the quotation the respondent may have thought that a single molecule or compound could move faster than two different molecules and it might have more entropy value than the reactants. The respondent states that reactants are in gaseous state, but did not note that the product is also in the gaseous state. Alternatively the respondent might have thought that the larger the molecule the larger the entropy value.

5.2.6 All combustion reactions produce H_2O (51)

This misunderstanding was related to general chemical knowledge and only observed in the pre-test for part (a) in 6% of responses. It is most probably due to confusion or over generalisation of the fact that combustion of organic compounds produces water and carbon dioxide. Students perhaps confused this fact with a normal combustion reaction.

5.2.7 Discussion

The source of the energy in a chemical reaction appears problematic for students from many points. Students perceived the energy associated in a chemical reaction rather differently from a chemist. The responses showed that students generally consider the energy in exothermic and endothermic reactions as different, because in many cases they give unlike reasons for the energy released in or required by the reactions. It seems that they have the notion that the energy in an endothermic reaction on the reactants side is only the activation energy and that exothermic reactions do not need activation energy. A significant proportion of the students (15%) reasoned that the energy in an endothermic reaction would be used to start the reaction. They also thought that the source of the energy in exothermic reactions was different from that of endothermic reactions. A small number of students mentioned that the energy released or required in a chemical reaction only depends on the total strength of the chemical bonds which are broken and formed before and after the reaction. In addition, many students still confused where the energy is required or the energy is released in a chemical reaction. This is perhaps due to considering the molecules or compounds as energy sources as discussed before. If we destroy them, they release energy and conversely when they form, they store energy. Alternatively, it may originate from extrapolating views about events in the macroscopic world into microscopic world - in the macroscopic world, energy is needed to make things; therefore, in the microscopic world, energy is also needed to make bonds as Boo (1998) suggests.

The responses revealed that some of the undergraduates still hold the same familiar misunderstandings such as that endothermic reactions cannot be spontaneous. They also revealed new misunderstandings such as *a spontaneous reaction must be exothermic* and *all formation enthalpies are exothermic.* Many students tried to attribute enthalpy changes to the entropy change of the system. Undergraduates misinterpreted and misused the idea that chemical reactions tend to proceed towards maximising entropy and minimising energy. In that statement the entropy is the entropy change of the universe not the entropy of the system, but students applied this to a system ignoring the accompanying changes in the surroundings. Consequently, it should be emphasised that teachers and lecturers should take care when they make generalisations since they can mislead students.

5.3 Magnesium

This question probes the students' understanding of enthalpy and internal energy change. The internal energy change and enthalpy change are frequently confused by the students. The difference between them is the transfer of energy as heat under constant volume or constant pressure. The diagram in the question (see the question in Appendix 8) was specially designed to represent both internal energy change and enthalpy change to determine the students' ability to select the correct one. For a detailed discussion of the expected answers of the question refer to the Appendix 8. The words *'heat'*, *'heat change'* and *'released heat'* are used by the students in the sense of *'the energy transferred as heat'* in the following sections. The results are summarised in Table 5.3.

Table 5.3 Analysis of the students' responses to ***Magnesium***

Code	Description	Pre-test (n=45)				Post-test(n=44)			
		a		b		a		b	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	10	22	14	31	18	41	20	45
10	**Uncodeable**	1	-	1	-	-	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	3	7	2	-	4	9	1	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	19	42	5	11	5	11	3	7
31	More heat is given out to the surroundings in the case of closed tap in apparatus **b**	14	31	-	-	5	11	-	-
32	This is an exothermic reaction	5	11	-	-	-	-	-	-
33	The energy is transferred as heat equals to the reaction enthalpy in apparatus a	-	-	5	11	-	-	3	7
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	15	33	21	47	12	27	19	43
41	Same amount of heat is given out to the surroundings in both apparatuses	3	7	-	-	2	-	-	-
42	More heat is given out in apparatus **a**	12	26	-	-	10	23	-	-
43	The released heat is equal to the reaction enthalpy change in the case of a closed tap (constant volume)	-	-	21	47	-	-	16	36
44	Enthalpy change is the energy transfer at constant volume	-	-	-	-	-	-	3	7
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	3	7	-	-	-	-	3	7
51	The gas has more kinetic energy in a smaller volume	3	7	-	-	-	-	-	-
52	Misunderstanding the constant pressure	-	-	-	-	-	-	3	7
60	**Sound understanding of the specific chemical idea tested in the question**	2	-	-	-	5	11	1	-

It can be seen from Table 5.3 that a relatively high percentage of the responses were blank for this question. For the sub-question (a), 22% of the pre-test responses were blank and this increased to 41% in the post-test. With respect to the sub-question (b), the percentage of the blank responses in the pre-test was 31% and increased to 45% in the post-test. It is also interesting to note that the percentage of blank responses in the post-test increased in contrast to the general trend that the number of the blank responses in the pre-test was higher than in the post-test. This high level of blank responses in the post-test may be due to the fact that enthalpy is a subject that was taught in the middle of the first semester. Since the post-test was applied at the end of second semester, students might have forgotten what they had been taught in the first semester. A few responses were uncodeable and the percentage of the responses which demonstrated no understanding of the specific chemical idea tested in the question ranged from less than 5% in the pre-test to 9% in the post-test.

The percentages of the responses which include some part of the accepted response was higher in the pre-test than the post-test. The answers for the sub-question (a) included more partial understandings in the pre-test (42%) than in the post-test (11%). There was a slight decrease in the number of responses which included partial understandings in the pre-test (11%) than in the post-test (7%) for the sub-question (b). The partial understandings were grouped into three categories. These were the ideas that *more heat is given out to the surroundings in the case of closed tap in apparatus b* (coded as 31), *it is an exothermic reaction* (coded as 32) and *the energy transferred as heat equals the reaction enthalpy in apparatus a* (coded as 33). The partial understanding, coded as 31, occurred with the highest frequency with 31% in the pre-test, dropping to 11% in the post-test. Another 11% of the pre-test responses included the both partial understandings

32 and 33. Only 7% of the post-test responses contained the partial understanding which was coded as 33.

The total percentage of the misunderstandings at the pre and the post-tests were similar, 33% and 27% respectively for sub-question (a). These figures increased to 47% and 43% respectively for sub question (b). The misunderstandings can be grouped under four headings. *The same amount of heat is given out to the surroundings at both apparatus* (coded as 41); this was observed in 7% of the pre-test and less than 5% of the post-test responses. The second misunderstanding is that *more heat is given out in apparatus (a)* (coded as 42) and was identified in 26% of the pre-test and 23% of the post-test responses. Amongst the misunderstandings, the highest percentage belonged to the misunderstanding that *the released heat is equal to the reaction enthalpy change in the case of a closed tap (constant volume)* (coded as 43); this was detected in 47% of the pre-test and 36% of the post-test responses. The final misunderstanding was identified in 7% of the post-test responses and stated that *enthalpy change is the energy transfer at constant volume* (coded as 44).

In addition, there were misunderstandings which occurred infrequently and are omitted from the table but are reported below:

- *The amount of the energy transferred as heat equals the reaction enthalpy change in both apparatuses*
- *Enthalpy change increases with the increase in the number of gas molecules*
- *The amount of heat given out increases with the increase in volume of the gas*
- *The rate of a reaction decreases with increased pressure*

Two more misunderstandings relating to general chemical knowledge were also identified. These are that *the gas has more kinetic energy in a smaller volume* (coded as 51) identified in 7% of the pre-test responses and *misunderstanding the constant pressure* (coded as 52) which was detected in 11% of the post-test responses.

Finally, none of the pre-test responses showed sound understanding the chemical idea tested in the question with the exception of two responses which were given to the sub question (a). However, 11% of the post-test responses did show sound understanding for sub-question (a) but again only one response showed sound understanding for sub-question (b). In the following section these misunderstandings will be examined more closely.

5.3.1 The same amount of heat is given out to the surroundings in both apparatuses (41)

This particular misunderstanding was identified in the responses from sub-question (a) with 7% in the pre-test and less than 5% in the post-test. The students argued that since the same reaction happens in both sets of apparatus with the same amount of reactants, the amount of heat transferred to the surroundings must be the same. The quotations below illustrate the students' arguments.

> *Since the same amount of reactants react in both apparatus, the amount of heat is given out will be the same ($ST_2/B/S_3$).*
>
> *As the reactants, amounts and the conditions are the same, the heat is released to the surrounding must be the same. There should not be a difference ($ST_2/B/S_{14}$).*

Students most often confused the energy transferred as heat to the surroundings with the total energy generated by the reaction. Students generally referred to the energy generated in a reaction as *'reaction heat'* or *'heat'*. They may have thought that energy can only be transferred as heat to the surroundings in a chemical reaction, but this depends on the conditions in which the reaction occurs. The energy generated in a reaction can be transferred to the surroundings as both heat and work. In this question, the total energy generated in the reaction and the energy transferred as heat to the surroundings are not the same in both sets of apparatus. In apparatus (a), in which the tap is open, some of the energy generated by the reaction was used to push back the syringe, so energy is transferred as work, and the rest of the energy transferred to the surroundings as heat. In the case of the closed tap in apparatus (b), all of the energy from the reaction is transferred to the surroundings as heat. Here students confused the energy generated from the reaction with the transfer of energy to the surroundings because they generally used the word *'heat'* instead of *'total energy'*. Carson and Watson (1999) found similar patterns in their study that students thought of enthalpy as a form of energy. Johnstone *et al* (1977) revealed that half of the secondary school pupils had the same misunderstanding. Only some of the students were aware of the fact that 'heat' and 'work' are two different ways of transferring energy. Roon (1992) and Roon *et al's* (1994) findings also support these results which once again show that more care is needed in the use of the language in teaching.

5.3.2 More heat is given out in apparatus (a) (42)

This was one of the most common misunderstandings being observed in 26% of the pre-test and 23% of the post-test responses. However it only appeared in the responses to sub question (a). It is persistent and has not been changed through teaching. Four groups of reasoning were identified in the examination of the responses. The first group just stated that more heat is given out to the surroundings in apparatus (a) and gave no explanation as to why. The second group argued that in the case of the open tap, the gas would expand and occupy a bigger volume, increasing the available surface where the energy transfer occurs as heat to the surroundings. A considerable proportion of the responses fell into this category and some typical quotations are given below:

> *In the apparatus (a), more heat is released to the surroundings. Because, the gas expands and heat takes more way. When I am answering this question I thought the stove example we use for heating at our homes (OT_2/E/S_9).*
>
> *...in apparatus (a), since the tap is open the gas pushes back the syringe and the volume of the gas increases, so the available surface, where the heat transfer to the surroundings occurs, increases. Thus, more heat is released to the surroundings in apparatus (a) (OT_2/E/S_{12}).*

The quotations clearly show that students misunderstood the transfer of energy as heat in this system as they compared it with the stove which is used for domestic heating. One of the major misunderstandings stems from the lack of knowledge of the system and its surroundings. The findings of this study are similar to Johnstone *et al's* (1977) study in which it was found that one in four pupils could not clearly distinguish between system and surroundings. Students thought that the energy was transferred as heat from the upper part of the system into different surroundings from those of the lower part of the system. In fact there is not only one system and its surroundings, the only difference is the available surface where the energy transfer occurs as heat. The increase of the available surface can increase the rate of the transfer of energy as heat but it does not affect how much energy is transferred as heat to the surroundings in total.

In the first quotation the respondent gives a stove as an example indicating where the energy transfer occurs as heat on the diagram by shading the area around the flask and syringe. It can normally be advised that increasing the length of the smoke pipes which carry the smoke from stove to chimney may helps get the maximum energy from the burning of fuel in stoves. The respondent compares the reaction system with such a similar system like a stove at home. This evidence supports the argument that everyday experiences may cause misunderstandings in science. Also, the terminology used plays an important role in the misunderstandings because 'heat' with a scientific meaning can be different from that used everyday language. In this quotation, the respondent presumably understood 'heat' as being similar to 'caloric value'. Here heat was thought of as a 'substance' which flows from place to place as compared with its present meaning in chemistry in which heat is accepted as the transfer of energy in every direction. These differentiating understandings have been identified by Fuchs (1987) and Driver (1994).

The third group of students' reasoned that there was a change in the equilibrium position of the reaction in the case of the open tap. Students thought that if the tap is open, the gas produced in the reaction will be removed from the flask and this will alter the position of the equilibrium towards the products and therefore the reaction will go to completion. But it was already stated in the question that both reactions reached to completion, so all of the reactants are used up. An increase in the available volume of the gas may increase the change in the rate of the reaction and also the possibility of completion sooner but it has no effect on the total energy generated from the reaction. Students probably either did not read the question carefully or they are not able to draw this conclusion from the diagram. The misunderstandings are illustrated in the following quotations.

> *More heat is given out in apparatus (a). Because the gas that has been produced by the reaction will get out the flask. Therefore the equilibrium position will be in favour of products. Thus the amount of heat given out will be more* $(OT_2/B/S_{15})$.
>
> *The more heat is released in apparatus (a). The tap is open and the gas that has been produced goes out of the flask. The reaction moves quickly towards products. As the reaction generates heat, thus more heat is released to the surroundings* $(ST_2/B/S_5)$.

Finally, some students attributed more heat being given out in apparatus(a) to the entropy change that accompanies to the reaction. They said that:

> *More heat is given out to the surroundings in apparatus (a). Because the gas in apparatus (a) expands into bigger volume. In this case entropy increase is more than in the case of closed tap apparatus. This causes more heat release to the surroundings* $(ST_2/E/S_{14})$.
>
> *The increase of entropy in apparatus (a) is more than that in apparatus (b).*
>
> $$\Delta S = q / T$$
>
> *Entropy is proportional to heat. Since the entropy of (a) is more than (b), more heat is releases into the surroundings in (a)* $(ST_2/E/S2_1)$.

In the second quotation, the entropy change of the system is considered instead of the entropy change of the universe. Students apply the facts which belong to the entropy change of the universe to the entropy change of the system. Granville (1985) also reports similar findings that especially students could not differentiate between the factors affecting the entropy. Many students thought that a volume increase was the only source of the entropy increase regardless of temperature change and other factors. These misunderstandings will be examined in detail in Chapter 6.

5.3.3 The heat change is equal to the reaction enthalpy change in the case of a closed tap (constant volume) (43)

This particular misunderstanding was the most common occurring in almost half of the pre-test responses (47%) and 36% of the post-test responses. It was only identified in the responses given to sub question (b). Some of the respondents stated that the released heat was equal to the enthalpy change of the system without giving an explanation. The students' arguments fell into four categories. Firstly, a small proportion of the respondents argued that there is no outside effect on the system in the case of the closed tap and therefore the energy released as heat should be equal to the enthalpy change of the system. This group of students perhaps misunderstood the diagram on the question. They understood that the syringe attached to the flask contained some hydrogen gas and it was added to the system gradually as the reaction proceeded. In contrast, the hydrogen gas in the syringe comes from the flask as the reaction proceeds. There is no addition of the gas into the system.

The second argument was that the reaction goes to completion in the closed apparatus and so the heat given to the surroundings is equal to the reaction enthalpy. It seems that there is a misunderstanding that the reaction does not go to completion in apparatus (a). In fact both reactions go to completion. The quotation below illustrates the case.

> *The heat released in apparatus **b** is equal to the reaction enthalpy change. Because of the closed tap the reaction goes to completion (OT_2/B/S_{21}).*

The third major argument was that in apparatus (b) no work was done by the system and all energy was transferred as heat. Students thought that if all the energy generated from the reaction is transferred as heat, it equals the reaction enthalpy regardless of considering the constant volume or constant pressure conditions. In fact this is only true if the reaction occurs under constant pressure, where the energy transferred as heat is equal to the enthalpy change of the system. Otherwise it is called an internal energy change if it occurs under constant volume. Students did not appreciate that the transfer of the energy as heat actually determines the names of the change. Students generally used the words 'reaction heat' for 'enthalpy change' or 'enthalpy', similar to Beall's (1994) findings. Also they were not aware of the fact that 'work' and 'heat' are different ways of transferring energy. They perceived them as totally different subjects and could not establish a relationship between them as illustrated below:

> *It equals the enthalpy change in apparatus* ***(b)****, because all of the energy generated in the reaction is equal to the enthalpy. There is no work done by the system* (ST_2*/E/*S_{10}*).*

> *It is in* ***(b)****, because the system is closed. There is no other way of transfer of energy except as heat. System is not doing work. However, in apparatus* ***a*** *some of the heat generated from the reaction used up to do work...*(ST_2*/E/*S_{21}*).*

From the second quotation it is also clear that the respondent has a lack of knowledge about the meanings of open and closed systems. Others were found to have no clear understanding of the distinction between system and surroundings.

Finally, some respondents tried to explain their answer by using the pressure of the gas in the flask after the reaction. Some even argued that pressure of the system is constant in the closed tap case,

> *The tap is closed in apparatus* ***(b)*** *and the heat released is equal to the reaction enthalpy, because pressure is constant* ($q_p = \Delta H_p$) (ST_2*/B/*S_{22}*).*

This respondent had given the correct definition of enthalpy but was not able to apply the information to the problem. The respondent was also not able to differentiate between the constant pressure and constant volume cases. This indicates that statements, facts and formulas were memorised rather than understood.

In addition to the above discussions, some of the students believed that the reaction which occurs in the closed tap apparatus generates more enthalpy change. They argued that if the tap is closed the pressure inside the flask will increase and this will cause an increase in the temperature of the gas. Thus more heat will be given to the surroundings compared to the open tap case. Here they confuse temperature and heat, and use them interchangeably which is common at secondary level but also prevalent at the undergraduate level.

5.3.4 Enthalpy change is the energy transfer at constant volume (44)

This misunderstanding was only detected in 7% of the post-test responses given to sub-question (**b**). The respondents confused the idea that enthalpy change is the energy transferred as heat under constant pressure as shown below:

> *It is (b), because it happens at constant volume (ST$_2$/E/S$_{13}$).*

This might also be because of the common mistake in confusing the constant pressure and constant volume cases.

In the following section two misunderstandings related to the general chemical / scientific knowledge will be discussed.

5.3.5 The gas has more kinetic energy in a smaller volume (51)

Similar misunderstanding was also discussed in the previous chapter (Chapter 4, section 4.2). It appeared again in this question. Only 7% of the pre-test responses revealed this misunderstanding. It had been stated that in the case of closed tap more energy will be released as heat to the surroundings because of the closed tap and constant volume conditions. Since the tap is closed, the available volume of the gas is less, therefore the gas must have more kinetic energy in a smaller volume. Students considered that the temperature of the gas will be high in this case. Here kinetic energy was also related to the amount of energy released as heat. In fact kinetic energy is proportional to the temperature of the gas and not to the amount of heat. This is most likely because of the well known misunderstanding that students perceived heat and temperature as the same (Brook *et al*, 1984 -1985).

5.3.6 Misunderstanding the constant pressure cases (52)

This misunderstanding was identified in only 7% of the post-test responses. Some of the respondents gave the correct definition of enthalpy but could not apply this to the problem. They said that the system is at a constant pressure in the case of the closed tap where it is actually at a constant volume. Typical quotations would be:

> *...it is in (b), because pressure is constant in (b) ($ST_2/B/S_9$).*
>
> *Since the pressure is constant in apparatus (b) the heat released to the surroundings must be equal to the reaction enthalpy,*
> $q_p = \Delta H$ *($ST_2/B/S_2$).*

Once again it is observed that undergraduates have a problem with very basic knowledge such as system and system conditions. They are not able to differentiate where the system is at constant pressure and where it is at constant volume. They thought that if the flask was closed, the pressure must be constant. They may believe that if the system is separated from the outside it becomes a constant pressure system.

5.3.7 Discussion

Magnesium revealed a number of students' misunderstandings in thermodynamics. Firstly, students perceived that the energy transferred as heat is equal to the enthalpy change of the reaction whatever the conditions are. It is also seen that students' understanding of *'heat'* and *'work'* is different from their meanings in thermodynamics. During the interviews, it was seen that the students' understanding of *'heat'* and *'work'* did not fit with their definitions in chemical thermodynamics. For example the following discussion suggests that undergraduates still see *'heat'* and *'work'* as a kind of energy, in fact they are different forms of energy transfer.

> *R: Heat and work are also confused concepts. Could you tell me what you know about these concepts?*
>
> *I: Heat and work...emm... I can only say that heat is energy...(long silence)*
>
> *R: So you say that heat is an energy.*
>
> *I: Yes, heat is an energy, I am sure.*
>
> *R: Where did you learn this?*
>
> *I: I learned this in high school.*
>
> *R: What about work?*
>
> *I: In fact work is also energy.*
>
> *R: Could you tell me if both of them are energy, then what is the difference between them?*
>
> *I: They are the kinds of energy. One of them [heat] is the energy gained because of the temperature difference, and the other,...emm...work is the energy gained because of the movement of a body (OI/B/S_1)*

The discussion also provides evidence that students retain existing knowledge of concepts learned in high school and it is difficult to override knowledge with new knowledge at a later stage.

In the following discussion the interviewee also defined 'heat' as a kind of energy. His understanding of *'work'* also showed that he still used the definition of work as used in physics instead of its meaning in chemical thermodynamics which is *energy transfer which causes the organised motion of atoms or molecules in the surroundings.*

> *R: Could you tell me what heat is?*
>
> *I: Heat is an energy for me, for example if we touch in a cold object it gets warm. There is a heat transfer there, I mean heat is a kind of energy.*
>
> *R: What can you say about work?*
>
> *I: Work is a force application...eee, it is the way that an object takes when a force has been applied on it (OI/E/S_5).*

It may be speculated that students find it easier to remember the definition of scientific concepts which have a connection with everyday life. *'Work'* has been taught in secondary school in physics in terms of the mechanical aspects, giving examples from everyday life such as pushing, lifting or rolling some objects. When students come across different definitions they struggle to integrate them with the previous ones and ultimately they continue to use previous knowledge.

Secondly, it is important to emphasise that none of the students mentioned that the internal energy changed even though the energy transferred as heat in apparatus (**b**) was equal to the internal energy change of the reaction. Almost half of the responses included the misunderstanding that the energy transferred as heat in apparatus (**b**) is the enthalpy change of the reaction. This result shows that students' knowledge of enthalpy change and internal energy change is not adequate. They do not have a clear distinction between internal energy change and enthalpy change. They are also unable to differentiate between constant pressure and constant volume situations and some even confuse open and closed systems.

Finally, students' misunderstandings have a close connection with the terminology used, everyday experiences and more importantly the students' fragmented or inadequate knowledge of basic ideas.

5.4 Two Hypothetical Reactions

This question probes undergraduates' misunderstandings in two areas. The first one is the comparison of the rate of chemical reactions by using thermodynamics quantities and the second is the spontaneity of chemical reactions. Both are well known misunderstandings at secondary level. *Two Hypothetical Reactions* finds out whether these misunderstandings are persistent among undergraduates. In sub-question (**a**), the idea being tested is the change in enthalpy which can be a guide to the stability of products and the reaction stability but gives no indication of the rate of a reaction. In sub-question (**b**), the undergraduates' understanding of the fact that both endothermic and exothermic reactions can be spontaneous is examined. The expected answers and the question can be seen in Appendix 8 and the results have been collected in Table 5.4.

Table 5.4 Analysis of the students' responses to *Two Hypothetical Reactions*

Code	Description	Pre-test (n=46)				Post-test(n=47)			
		a		b		a		b	
		f	%	f	%	f	%	f	%
00	**Blank**	6	11	2	-	5	11	4	9
10	**Uncodeable**	-	-	3	6	2	-	3	6
20	**No understanding of the specific chemical idea tested in the question**	1	-	4	9	1	-	3	6
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	17	37	35	76	19	40	27	57
31	It is not possible to compare the rate of these reactions	10	22	-	-	14	30	-	-
32	The initial concentration of the reactants should be known to make a comparison	3	6	-	-	-	-	-	-
33	The rate of the slowest step determines the rate of bi or uni-molecular reactions	1	-	-	-	3	6	-	-
34	Temperature increases the rate of the endothermic reactions but conversely effects the rate of the exothermic reaction	3	6	-	-	2	-	-	-
35	$\Delta G < 0$ for a spontaneous reaction (But only at constant T and P)	-	-	4	9	-	-	2	-
36	The spontaneous occurrence of an exothermic reaction is more common than an endothermic reaction	-	-	6	13	-	-	4	9
37	Exothermic reaction spontaneously occur	-	-	17	37	-	-	14	30
38	Exothermic reactions spontaneously occur but spontaneity of an endothermic reactions depend on the energy supplied bt the surroundings	-	-	5	11	-	-	6	13
39	Entropy change that accompanies the reactions also should be known to decide spontaneity of these reactions	-	-	3	6	-	-	1	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	28	61	20	43	19	40	13	28
41	Exothermic reactions occur faster	12	26	-	-	12	26	-	-
42	Endothermic reactions occur faster	7	15	-	-	4	9	-	-
43	Endothermic and exothermic reactions occur at the same rate if the medium temperature is the same	3	6	-	-	1	-	-	-
44	Only temperature of the medium affects the rate of a reaction	3	6	-	-	1	-	-	-
45	The rate of the reaction is only estimated from the concentration of the products	3	6	-	-	1	-	-	-
46	Endothermic reactions cannot be spontaneous	-	-	17	37	-	-	12	26
47	Endothermic reactions can be spontaneous but exothermic reactions cannot be spontaneous	-	-	3	6	-	-	1	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	6	13	-	-	2	-	-	-
51	Misunderstanding heat and temperature	3	6	-	-	-	-	-	-
52	Misunderstanding exothermic and endothermic reactions	3	6	-	-	2	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	2	-	1	-	4	9	11	23

It can be seen that this question generated a wide range of responses. 11% of the responses for sub question (**a**) were blank in both the pre and the post-test and 9% of the post-test responses for sub question (**b**) were also blank. Few responses in the post-test were uncodeable for sub-question (**b**) and also 9% of the pre-test and 6% of the post-test responses demonstrated no understanding of the specific chemical idea tested in the question.

The responses also included partial understanding the specific chemical idea tested in the question. Sub question (**b**) generated more partial understandings than (**a**). Almost 40% of the pre and the post-test responses for (**a**) included some part of the accepted response while this increased to 76% in the pre-test and 57% in the post-test for (**b**). The partial understandings were grouped under a total of nine headings. The first one, and a common one, was that *it is not possible to compare the rate of these reactions* (coded as 31), seen in 22% of the pre and 30% of the post-test responses. Some 6% of the pre-test responses included the fact that *initial concentration of the reactants should be known to make a comparison* (coded as 32), and also another 6% of the post-test responses included the fact that *the rate of the slowest step determines the rate of bi or uni-molecular reactions* (coded as 33). In addition, 6% of the pre-test responses and less than 5% of the post-test responses contain the fact that *temperature increases the rate of endothermic reactions while it conversely effects the rate of exothermic reactions* (coded as 34). Almost 10% of the pre-test responses stated that *ΔG (0 for a spontaneous reaction (but only at constant T and P)* (coded as 35). It should be noted that none of these responses commented that this statement is only true at constant T and P. *The spontaneous occurrence of an* *exothermic reaction is more common than an endothermic reaction* (coded as 36) was identified in 13% of the pre-test and 9% of the post-test responses. The majority of the responses (37% at the pre and 30% in the post-test) included the fact that *exothermic reactions occur spontaneously* (coded as 37). The idea that *exothermic reactions spontaneously occur but spontaneity of an endothermic reaction depends on the energy supplied from the surroundings* (coded as 37) was shown in 11% of the pre-test and 13% of the post-test responses, and finally *entropy change accompanying the reactions also should be known to decide spontaneity of these reactions* (coded as 39) was seen in 6% of the pre-test responses.

The responses also included a number of misunderstandings including some previously prevalent ones. In total, 61% of the pre-test and 40% of the post-test responses for sub question (a) included seven misunderstandings. Five of them were related to specific chemical idea tested in the question and two of them were related to general chemical knowledge. 43 % of the pre-test and 28% of the post-test responses given to sub-question (b) included misunderstandings which were related to the specific chemical idea tested in the question. A high percentage of the responses included the misunderstandings that *exothermic reactions occur faster* (coded as 41), detected in one quarter of the responses, and *endothermic reactions occur faster* (coded as 42), detected in 15% of the pre and 9% of the post-test responses. The misunderstanding that *endothermic and exothermic reactions occur at the same rate if the temperature of the medium is the same* (coded as 43) was seen in 6% of the pre-test and very few of the post-test responses. The following misunderstandings, *only the temperature of the medium* *affects the rate of a reaction* (coded as 44) and *the rate of a reaction is only estimated from the concentration of the products* (coded as 45) were identified in 6% of the pre-test and less than 5% of the post-test responses. The most common one was a well known misunderstanding that *endothermic reactions cannot be spontaneous* (coded as 46) and was identified in 37% of the pre-test and 26% of the post-test responses. The final misunderstanding relating to the specific chemical idea tested in the question was that *endothermic reactions can be spontaneous but exothermic reactions cannot be spontaneous* (coded as 47) and was detected in 6% of the pre-test responses.

Two misunderstandings relating to general chemical knowledge were detected. Those are, *misunderstanding heat and temperature* (coded as 51) and *misunderstanding exothermic and endothermic reactions* (coded as 52) and were identified in 6% of the pre-test and very few of the post-test responses. A number of misunderstandings are listed below but are not shown in the table because the frequency was less than 5%.

- *To be able to compare the rate of the reactions numerical value of the enthalpy changes of the reactions should be known*
- *The temperature of the medium has no effect on exothermic reactions*
- *The rate of a reaction depends only on the entropy change*
- *The rates of these reactions can only be estimated if the reactants and the products are known*
- *Spontaneity of a reaction only depends on the activation energy of a reaction*
- *If a reaction occurs without outside intervention it is called spontaneous*

The number of responses which included a sound understanding was less than

5% in the pre-test but increased slightly in the post-test to 9% for (a) and to 23% for (b). The detailed discussion of the identified misunderstandings is contained in the following sections.

5.4.1 Exothermic reactions occur faster (41)

Almost a quarter of the respondents in both the pre-test and the post-test argued that exothermic reactions occur faster. The most common reasoning was that exothermic reactions release energy, therefore they occur faster because there is no barrier to prevent the occurrence of a reaction. Students confused the rate of a reaction with the spontaneous occurrence of a reaction. This is because, at a certain temperature, the amount of energy required or released can indicate the stability of the reaction as well as being a sign of the spontaneous occurrence of a reaction. However it does not provide information how fast it occurs. The accompanying entropy change of the universe should not be ignored. Some typical responses are as follows:

> *The first reaction is an exothermic reaction. There is no need for energy to happen the this reaction in contrast the second reaction. The products releases energy, and they are more stable because they have less energy. Therefore the first reaction occurs faster (OT_f/B/S_1).*
>
> *An exothermic reaction happens more easily and faster. Because it is easier to release energy than to get the energy even if the ambient temperature is the same. Therefore exothermic reactions occur faster (OT_f/B/S_{16}).*

It seems from the second quotation that the respondent confused 'energy' as used in chemistry with 'energy' as used in everyday language because the 'energy' we mention in everyday language is something that always has a cost and an effort is required to get it. In addition, some of the respondents approached the problem from the point of view that less energy means more stability. Since the total energy of the products is less than that of reactants in exothermic reactions, they thought that chemical reactions should occur towards to the lower energy direction regardless of considering the factors alter the rate of a reaction.

One of the respondents argued that the first reaction occurs fastest, because the temperature of the system increases as the reaction occurs, thus the rate of the reaction increases gradually. In another response it was argued that as exothermic reactions occur spontaneously, they also occur faster. The quotations show that a significant proportion of the undergraduates are still unaware of the fact that it is not correct to make an estimation about the kinetics of a chemical reaction by using thermodynamic quantities. Some of these misunderstandings may be due an inability to differentiate the kinetic and thermodynamic data.

5.4.2 Endothermic reactions occur faster (42)

This particular misunderstanding was identified at lower percentages compared to the previous one (41). 15% of the pre-test responses included this and it dropped to 9% in the post-test. The responses centred around the idea that the rate of exothermic reactions is conversely affected by the temperature increase but increase in temperature positively affects the rate of endothermic reactions. Since the reactions occur at a certain temperature, the required energy is available for the endothermic reactions, therefore they happen faster. The following quotations illustrate this.

> *The colder the ambient temperature the faster the exothermic reactions occur. The hotter the ambient temperature the faster the endothermic reactions occur. Since there is a certain ambient temperature the endothermic reaction should occur faster (ST_1/E/S_2).*

The quotation shows that the respondent confused the ambient temperature and the optimum temperature at which a reaction occurs with a maximum yield. The respondent might also confuse heat and temperature because s/he mentioned the words 'cold' and 'hot' and takes the T temperature as hot. This is similar to previous misunderstanding (41) in which students confuse kinetic and thermodynamic data.

5.4.3 Endothermic and exothermic reactions occur at the same rate if the temperature of the medium is the same (43)

This misunderstanding was less common compared to the previous two, with only 6% of the pre-test responses and less than 5% of the post-test responses including it. It was argued that at the same temperature the rate of both exothermic and endothermic reactions should be the same.

> $Rate_1 = k_1[A][B]$
> $Rate_2 = k_2[E][F]$
> *Since the temperature is the same the rate constants are the same. Therefore the rate of these reactions should be the same (OT_1/E/S_{19}).*

In the quotation, the respondent gives the correct statement for the rate constants of the reactions, but it is not possible to say that the rate of a reaction only depends on the rate constant of a reaction regardless of the concentrations of the reactants, surface area etc. It can be argued that the rate constant of a reaction depends on the temperature of the system. However, it is not the only factor that alters the rate of a reaction.

5.4.4 Only the temperature of the medium affects the rate of a reaction (44)

A few of the responses in the pre-test (6%) and less than 5% of the responses in the post-test included this particular misunderstanding. It was argued that, as shown below, the rate of a reaction only depends on the temperature.

> *The rate of chemical reactions depend only on the temperature...*($OT_f/B/S_1$).
>
> *The only factor which affects the rate of a reaction is temperature...*($ST_f/E/S_{10}$).

These respondents may have misunderstood the fact that the rate constant of a reaction changes with temperature instead of the rate of a reaction or they just did not know the difference between them.

5.4.5 The rate of a reaction is only estimated from the concentration of the products (45)

This is also one of the least frequently occurring misunderstandings, being identified in only 6% of the pre-test and less than in 5% of the post-test responses.

> *To be able to make a comparison between the reaction rates, the concentration of the products should be given. Because the reaction rates can only be estimated from the products concentrations* ($OT_f/E/S_8$).

The respondent argues that reaction rate equations are given by the concentration of the products. In fact it is not necessary to use product concentrations. Reactant concentrations can also be used to calculate the rate of a reaction. This kind of misunderstanding might either come from memorising the facts incorrectly or misinterpreting the statements.

5.4.6 Endothermic reactions cannot be spontaneous (46)

This misunderstanding is common among secondary school students and undergraduates. It appeared again in this study in high percentages; 37% in the pre-test which decreased by approximately 10% in the post-test. Johnstone *et al* (1977) reported that one pupil in six was still hampered by the idea that endothermic reactions could not be spontaneous (p. 248). They argue that this is carried over from the apparently universal rule that reactions tend spontaneously towards a lower energy level. More recently Thomas *et al* (1998) reported that three quarters of the undergraduates taking a physical chemistry course at advanced level still subscribed to this view.

All of the respondents approached spontaneity from an energy point of view and none of them mentioned that an entropy change occurs in the universe as a result of a chemical reaction. They argued that, since endothermic reactions require energy to occur, they cannot be spontaneous. This is a slightly different expression of Johnstone *et al*'s (1977) argument. This approach might be due to the consideration of one aspect of the spontaneity. In fact enthalpy is one of the most important components of the Gibbs energy which helps to determine the tendency to spontaneous occurrence of a reaction at constant T and P. However, students failed to consider entropy which is the other important component. This misunderstanding might stem from a lack of knowledge about what spontaneity is, as Ribeiro *et al* (1990) reported. In their study undergraduates argued that a chemical reaction is spontaneous if we do not need to interfere or if it is observable. This can be seen in the quotations below:

> *...the second reaction requires heat to occur. There is a need for energy. I mean it only can occur with an outside interference ($OT_1/B/S_4$).*
>
> *As they require heat, endothermic reactions cannot be spontaneous ($OT_1/E/S_{18}$).*
>
> *The second reaction requires energy to provide the activation energy. Therefore the second reaction cannot be spontaneous ($OT_1/E/S_5$).*

There are two approaches, one from the energy viewpoint and the other from an understanding of spontaneity. The respondents thought that if energy is needed from the outside to stimulate the reaction, it cannot be spontaneous. In order to be a spontaneous reaction, there should be no interference from outside the reaction system.

5.4.7 Endothermic reactions can be spontaneous but exothermic reactions cannot be spontaneous (47)

This was the final misunderstanding relating to the specific chemical idea tested and identified in 6% of the post-test responses and less than 5% of the post-test responses. The respondents confused endothermic and exothermic reactions and expressed this idea as shown below:

> *The first reaction requires heat but the second one releases heat... therefore the second one can be spontaneous but the first reaction cannot be spontaneous* (OT_f*/B/*S_{11}*).*

The respondent either does not understand exothermic and endothermic reactions or has simply misunderstood the definition of spontaneity. The rest of the responses only included the statement that endothermic reactions can be spontaneous but exothermic reactions cannot be spontaneous. Neither response was accompanied by an explanation therefore it is not easy to draw a conclusions.

In the next section of the study the two misunderstandings relating to general chemical knowledge will be discussed.

5.4.8 Misunderstanding heat and temperature (51)

A small percentage of the responses showed some misunderstandings about heat and temperature. One of the respondents confused the sign of the energy transferred as heat with temperature by stating that:

> *...the temperature is negative in exothermic reactions and it is positive in endothermic reactions...* (OT_f*/E/*S_3*).*

The negative and positive signs show the energy released or energy required by a reaction, not the temperature of the system. In addition some of the students made statements like:

> *The rates of these reactions depend on the ambient temperature and the temperature required or released in the reactions ($OT_1/E/S_{13}$).*

It is clear that this respondent does not distinguish between temperature and heat. Although few respondents showed this misunderstanding in the written responses, it was observed with a much higher frequency in the interviews. Heat was also confused with the definition of a 'calorie' in same cases.

> *R: You have just mentioned heat energy haven't you? Could you tell me what you mean by heat energy?*
>
> *I: ...(pause) It is the amount of energy that it should be given to increase the temperature of a certain amount of water by 1°C.*
>
> ...
>
> *R: So could you tell me what is the difference between heat and temperature?*
>
> *I: Heat is energy. Temperature...(long silence) I can't make a proper definition but heat exists due to temperature. I mean heat occurs because of temperature. There is a heating but,.. I can't explain. I have something in my mind but,...*
>
> *R: Can you give an example of what you have in your mind?*
>
> *I: Emm,... for example, emm.. if we put some water on a fire its temperature increases and we give it heat energy proportional to the temperature ($OI/B/S_6$).*

The interviewee defined heat as a calorie as well as considering that heat is the result of temperature change. This might be due to the conventional definition that heat is the energy which flows from hot to cold objects. The following discussion also shows that undergraduates misunderstood the above definition of heat.

> *R: Could you tell me what you know about enthalpy?*
>
> *I: Enthalpy reminds me of heat. In an endothermic reaction heat is supplied, if the reaction is exothermic heat is released then.*
>
> *R: OK, so what is the heat then?*

> *I: Heat is the way of flow of the temperature from one object to another.*
>
> *R: Could you repeat what you said in the last sentence for me please, I couldn't get exactly what you mean?*
>
> *I: Yes, I mean, it is the way of exchange of temperature between two objects.*
>
> *R: So, in this case how would you define the temperature?*
>
> *I: Temperature is the energy exchange between two objects.*
>
> *R: Can you give me an example what kind of energy exchange you mean?*
>
> *I: For instance, if we put together two objects when they are at different temperatures, there will be a heat transfer until their temperatures are equal. In thermal equilibrium their temperatures are the same. I mean, the temperature is this energy that is exchanged* (OI/E/S_6).

The interviewee had no clear understanding of heat and temperature, a common misunderstanding which is well known and well documented in the literature Studies such as Brook *et al* (1984, 1985) show similar findings. In their study, 15 year olds thought that *'heat and temperature are the same'*. In this study undergraduates did not state this directly but their answers denote that they still use the terms 'temperature' and 'heat' interchangeably.

5.4.9 Misunderstanding exothermic and endothermic reactions (52)

This final misunderstanding was only diagnosed in 6% of the pre-test responses and only one response in the post-test. Respondents gave statements like:

> *An exothermic reaction is a reaction that requires energy to occur, and an endothermic reaction is a reaction that releases energy when it occurs...* (OT_1/E/S_4).

This confusion is common amongst secondary level Turkish pupils, because the foreign words 'exothermic' and 'endothermic' are used in the textbooks and also by the teachers. Students need to memorise these terms and subsequently find it difficult to differentiate between them and use them correctly. This is mostly a language related misunderstanding which often persists throughout undergraduate level.

5.4.10 Discussion

The differentiation between kinetics and thermodynamics, and the understanding of spontaneity seem particularly unclear in undergraduates' minds. *Two Hypothetical Reactions* explored a number of student misunderstandings resulting in a relatively low percentage of blank responses but a high percentage of partial understandings indicating fragmented knowledge.

Students tend to apply general rules to particular cases ignoring any conditions on its application. In many cases they appear unaware of the circumstances in which the statement/s can be applied. One of the best examples is the generalisation that if $\Delta G \langle 0$ a chemical reaction occurs spontaneously. None of the respondents mentioned that this statement is only true under isothermal conditions and constant pressure (constant T and P). As Granville (1985) argues, students quickly adopt it as a general criterion regardless of other circumstances. If a process is not isobaric (constant P) then the Helmholtz Energy (ΔH) should be used at constant volume. For non isothermal cases, there is no generally useful relationship between spontaneity and the sign of ΔG or ΔH. This time ΔS must be used (Granville 1985, p. 848).

From the misunderstandings it is clear that students make no clear distinction between reaction kinetics and thermodynamics and try to use thermodynamic data to explain the kinetics of a reaction. This kind of approach was also detected during interviews where typical comments were:

> *R: Ok I will ask you another question then. According to you, can we make a guess about the rate of a reaction by looking at enthalpy change in a reaction?*
>
> *I: If I can relate it with activation energy, we can say, according to the activation enthalpy, ...emm, products' enthalpy, reactants' enthalpy, eee we should be able to make a guess (SI/B/S_{12}).*

In many cases during the interviews students used thermodynamic data such as entropy, enthalpy or Gibbs energy value of a reaction to estimate the rate of a reaction, which is related to kinetics. These misunderstandings may originate from students' experiences as explained in section 5.4.1. Some may be language related as in misunderstanding (52). Students unsettled knowledge about the subjects and straight memorisation should be considered as well.

5.5 Ice Melting

Ice Melting tests the students' understanding of the fact that enthalpy is an extensive property. This means that the enthalpy of a substance depends on the amount of the substance in the sample. In contrast to extensive properties, intensive properties are independent of the amount of the substance in the sample. The best example to differentiate extensive and intensive properties are heat and temperature. Heat is an extensive property which depends on the amount of the substance in the sample but temperature is independent of the amount of the substance in the sample. The question and expected answer can be seen in Appendix 8. The results are displayed in Table 5.5.

Table 5.5 Analysis of the students' responses to *Ice Melting*

Code	Description	Pre-test (n=45)		Post-test (n=44)	
		f	%	*f*	%
00	**Blank**	3	7	4	9
10	**Uncodeable**	3	7	1	-
20	**No understanding of the specific chemical idea tested in the question**	3	7	2	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	13	29	8	18
31	During dissolving of KI more heat is absorbed from the surrounding water	13	29	8	18
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	18	40	25	57
41	The dissolution of NaCl is an exothermic process	5	11	10	23
42	During the dissolution of NaCl more heat is absorbed from the surrounding water	13	29	15	34
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	3	7	1	-
51	Misunderstanding melting and dissolving	3	7	1	-
60	**Sound understanding of the specific chemical idea tested in the question**	5	11	8	18

This question generated a narrower range of responses and also fewer misunderstandings compared to previous questions. Most of the responses only focussed on the information given in the question and only a few were blank. The blank response percentages were only 7% in the pre-test and 9% in the post-test. In addition, 7% of the pre-test responses were uncodeable. Another 7% of the pre-of test and less than 5% of the post-test responses demonstrated no understanding of the specific chemical idea tested in the question. A significant percentage of the responses (29% of the pre and 18% of the post-test) contained the notion that during the dissolving of KI more heat was absorbed from the surrounding water (coded as 31).

Two misunderstandings relating to the specific chemical idea tested in the question were identified. A considerable number of responses in the pre-test (11%) and the post-test (23%) argued that *the dissolution of NaCl is an exothermic process* (coded as 41), and a significant percentage (29% of the pre-test and 34% of the post-test) of students argued that *during the dissolution of NaCl more heat is absorbed from the surrounding water* (coded as 42). In addition, 7% of the pre-test responses included the *misunderstanding of melting and dissolving* (coded as 51). Some misunderstandings relating to general chemical/scientific knowledge observed at lower percentages are listed below:

- *Misunderstanding of absorption and adsorption*
- *The melting of ice is an exothermic process*
- *Bond breaking releases energy while bond making requires energy*
- *Dissolving of salts is not affected by temperature change*

Finally, the number of the responses which showed a sound understanding increased from 11% in the pre-test to 18% in the post-test. In the following sections the misunderstandings which were identified will be examined in detail.

5.5.1 The dissolution of NaCl is an exothermic process (41)

This particular misunderstanding was identified at a relatively lower percentage in the pre-test (11%) compared to the post-test (23%). The responses centred around two headings. The first group of respondents argued that the dissolution of NaCl is an exothermic process while the second group argued that the dissolution of NaCl is an exothermic process and the dissolution of KI is endothermic. In the question it was stated that both of the salts absorb heat when they dissolve but students did not realise this. Most of them thought that if no ice was left in the container this was because when the NaCl dissolved some heat was generated by the dissolution process and this melted the ice in the container. This can be seen from the below quotations.

> *... heat must be given to the surroundings to melt the ice. I mean the dissolution of salt must be exothermic. When NaCl dissolves it releases heat and ice melts. In contrast, KI absorbs heat ($ST_2/E/S_1$).*
>
> *NaCl must release heat to melt the ice...($ST_2/E/S_{12}$).*
>
> *...Since the dissolution of NaCl is exothermic, the heat released melts the ice. The dissolution of KI is endothermic ($ST_2/B/S_3$).*

Students attributed the melting of ice in the container where NaCl was added to so-called generated heat. They thought that it was an exothermic process even though it was indicated that both are endothermic reactions by stating that they absorb heat when dissolved. They perhaps thought that the only source of heat was the dissolution process as the amount of energy stored in the surrounding water was considered. Only a few of the responses mentioned the energy required to dissolve the salts being supplied by the surrounding water.

Misunderstandings may originate from two sources; one may be the students' lack of knowledge about the relationship between the system and its surroundings as students did not take the energy stored in the surroundings into consideration. The other possible source may be the misunderstanding that bond breaking releases energy while bond making requires energy. This kind of approach is evident in the following quotation.

> *... energy is required when bonds form, while energy is released during bond breaking. The melting of the ice in the beaker in which NaCl is added shows that more heat released during dissolving of NaCl (breaking bonds). I mean more heat is released to the surroundings and ice was melted ($OT_2/E/S_3$).*

It was also clear that students thought that dissolving only includes the breaking of the bonds of the dissolved compound. They did not consider the hydration of the ions, which is an exothermic process, after dissociation.

5.5.2 During the dissolution of NaCl more heat is absorbed from the surrounding water (42)

This misunderstanding was detected in one third of the responses at both the pre-test and post-test. The figures show that the frequency of this misunderstanding has not changed as a result of teaching and it is resistant to change by traditional teaching methods. The examination of the responses showed that students confused the relationship between system and surroundings, because they could not differentiate between where the energy comes from and where it goes to.

They also confused the absorption of heat from the surroundings and some of them thought that heat is absorbed from the outside of the beaker. Normally the surroundings of the ice/water and dissolved salt system consists of water and the energy is primarily absorbed from the water during dissolution of salts, not from the outside of the beaker. This misunderstanding can be seen in the following quotation.

> *The amount of absorbed heat is more in the NaCl added beaker, because the amount of absorbed heat from the outside of the beaker must be more to melt the ice quickly (ST$_2$/B/S$_1$).*

Some of the students thought that NaCl absorbs heat and then transfers it to the ice to melt it, demonstrating that absorption of heat is misunderstood. This is shown in the following quotations.

> *During the dissolution of NaCl more heat is absorbed. The ice in the beaker in which NaCl is added is melted. Since NaCl uses the heat absorbed from the surrounding to melt the ice... (ST$_2$/B/S$_1$).*
> *NaCl absorbs more heat, because the ice in the beaker in which NaCl is added melts*

> *quickly. NaCl causes the melting of the ice because it absorbs more heat* (*$OT_2/B/S_4$*).

In the first quotation, it is not clear exactly why the respondent gave this answer but possibly he/she thought that in absorption energy was given to the surrounding water and this caused the melting of ice. In the second quotation the respondent argues that NaCl absorbs heat and uses it to melt the ice in the beaker. In this context NaCl was thought of as something like a heat transfer agent. From these answers and other similar responses it is clear that students are not able to differentiate that the source of the energy is the surroundings. This is perhaps because of lack of knowledge about the system and surrounding boundaries.

5.5.3 Misunderstanding melting and dissolving (51)

This misunderstanding is related to general chemical / scientific knowledge and was only identified in 7% of the pre-test responses and only in one response in the post-test. It is known that younger students misunderstand these concepts, but this study showed that a small percentage of the undergraduates held this misunderstanding. Mainly students used the term 'melting' instead of 'dissolving'. This is shown in the following quotation.

> *While NaCl melts, it releases heat to the surroundings, it cannot hold the heat...*(*$OT_2/B/S_{13}$*).

5.5.4 Discussion

It should be noted that this question generated a narrow range of responses and misunderstandings and did not encourage students to give responses from different perspectives. Extensive and intensive properties are not understood by the students. Some of the responses suggested that the respondents even did not appreciate the subject of the question therefore tried to answer it by applying general principles. They thought that if ice melts in the beaker in which NaCl was added there must be an exothermic reaction, because melting of ice is an endothermic process and requires energy. Students basically thought that the heat melting the ice was coming the dissolution reaction and therefore around 20% of the respondents argued that the dissolution of NaCl must be exothermic. Boo (1998) found that A-level students had difficulties in identifying endothermic and exothermic reactions.

Students also showed a poor understanding of system-surroundings relationships and would not differentiate between the borders of the system and its surroundings. The fact that the heat that melted the ice was supplied by the surrounding water was not acknowledged. Moreover, a widely held misunderstanding that bond breaking releases energy while bond making requires energy seems to be a major source of misunderstanding because students thought that the dissolution of salts involves only the disassociation of the compounds. In many cases they did not consider the hydration of the ions in the water after disassociation. Finally, this question showed that a considerable number of undergraduates still confuse melting and dissolving.

5.6 Conclusions

This chapter provides a comparison of students' misunderstandings about enthalpy before and after teaching in the physical chemistry course. Students' responses provide evidence of significant misunderstandings.

Responses to *Copper(II)Sulphate* (section 5.1) suggest that almost two thirds of the respondents are unable to recall the enthalpy changes indicated on an energy level diagram. A majority of the students cannot define or describe the names of the enthalpy changes given to the different processes, such as lattice, solution and hydration enthalpy. Students are most likely to confuse lattice enthalpy with sublimation, formation and activation enthalpy.

The hydration enthalpy is widely confused with formation and solution enthalpy, as well as activation and ionisation enthalpy. The students' ability to recognise an enthalpy change on an energy level diagram by drawing an arrow to indicate the related enthalpy change is also weak. More than one third of the responses revealed misunderstandings in the pre-test, but the figures showed improvements after teaching. Finally, a majority of the respondents cannot draw a conclusion from an energy level diagram as to whether the reaction is exothermic or endothermic.

Responses to the question *Energy* (section 5.2) concerning the source of the energy generated or used in a chemical reaction revealed a number of misunderstandings. Some of these were previously identified such as *"bond breaking releases energy while bond making requires energy"* and *"endothermic reactions cannot be spontaneous"*. In addition students have misunderstandings such as that *"formation enthalpy is always exothermic"* and *" a spontaneous reaction is always exothermic"*. Students appear to understand the source of energy as different in exothermic and endothermic reactions. A small number of respondents can actually provide an explanation that energy is stored in the chemical bonds, therefore the energy change of a reaction is related to the strength of the bonds made and broken in a reaction.

Responses to *Magnesium* (section 5.3) suggest that the majority of the students make no clear distinction between *"heat"* and *"reaction enthalpy"*. In many cases, they also showed poor understanding of *"heat"* and *"work"* in thermodynamics. Language seemed to have an apparent effect in the origin of the misunderstandings. In addition, the students' ability to differentiate the enthalpy change and internal energy change is found to be weak. Almost half of the students are not able to recognise enthalpy change in a constant pressure system and furthermore they cannot differentiate between the constant pressure and constant volume cases. This causes them to have difficulty in distinguishing the enthalpy and internal energy changes. Poor understanding of the system and surroundings relationship is still a persistent problem.

With respect to the question *Two Hypothetical Reactions* (section 5.4) responses showed a wide range of misunderstandings but showed improvements in the post-test. Most commonly students argued that *exothermic reactions occur fast* and that *endothermic reactions cannot be spontaneous*. It appears that the majority of students cannot differentiate between reaction kinetics and thermodynamics. In addition, spontaneity seems to be still vague in their minds. Students have an inclination to apply general statements to every case regardless of any constraints.

Finally, responses to *Ice Melting* (section 5.5) suggest that students have a poor understanding of the relationship between system and surroundings and also enthalpy change involved in chemical reactions. Exothermic and endothermic reactions are unclear in the students' minds, just as they have problems over dissolution and dissociation and with 'dissolving' and 'melting'.

Chapter 6

Chapter 6

Analysis of The Responses About *Entropy and Related Ideas*

This chapter reports the analysis of the students' responses to four questions about entropy and related ideas. These are *Seawater*, *Mixing of Gases*, *Spontaneous Change* and *Carbon Dioxide and Propane*. Each question will be discussed separately in the following sections.

6.1 Seawater

Seawater (see Appendix 8) probes students' understanding of entropy changes which happen in a system and its surroundings. When changes occur in a system, there are nearly always accompanying changes taking place in the surroundings. The idea being tested in this question has a practical application in daily life like putting salt on icy roads. The idea being tested in the question was that any process which increases the number of particles in the system, increases the number of microsystems and also increases the entropy of the system. Table 6.1 summarises the results.

As shown in Table 6.1, 29% of the pre-test responses for **(a)** and 51% of the post-test responses for **(b)** were blank. This percentages dropped to 9% for **(a)** and 36% for **(b)** in the post-test. The high number of blank responses, especially for sub-question **(b)**, indicates that students have insufficient knowledge about entropy especially at the beginning of the semester. Sub-question **(b)** concerns the entropy change of the surroundings and it gets a lower response rate compared to sub-question **(a)**.Only one response in the post-test was uncodeable.

Table 6.1 Analysis of the students' responses to *Seawater*

Code	Description	Pre-test (n=45)				Post-test(n=44)			
		a		b		a		b	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	13	29	23	51	4	9	16	36
10	**Uncodeable**	-	-	-	-	-	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	2	-	5	11	2	-	11	25
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	25	57	8	18	17	37	4	9
31	Entropy is the measure of disorder	2	-	-	-	3	6	-	-
32	Diagram a represents the entropy change of the seawater when it freezes	23	51	-	-	11	25	-	-
33	$\Delta S = q / T$ or $\Delta S = \Delta H_{freezing} / T_{freezing}$	-	-	-	-	3	6	-	-
34	When the seawater freezes the magnitude of the entropy change of the surroundings is bigger than that when pure water freezes	-	-	8	18	-	-	4	9
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	2	-	2	-	4	-	7	16
41	Diagram b represents the entropy change of the seawater when it freezes	2	-	-	-	4	9	-	-
42	Entropy change of the surroundings is the same on both occasions	-	-	2	-	-	-	3	6
43	The magnitude of the entropy change of the surroundings is bigger when pure water freezes than when seawater freezes	-	-	-	-	-	-	4	9
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	4	9	6	13	21	48	5	11

The number of the responses which demonstrated no understanding of the specific chemical idea tested in the question increased from 10% in the pre-test to 30% in the post-test for a total of (a) and (b). This increase can be partly attributed to the increase in the number of students who attempted to answer the question. The responses also showed a higher percentage of partial understandings in the pre-test than the post-test. More than half (57%) of responses given to sub-question (a) and 18% of the responses given to sub-question (b) in the pre-test demonstrated partial understanding. These figures dropped to 37% for (a) and 9% for (b) in the post-test. The responses yielded partial understandings in four categories. These are *entropy is the measure of disorder* (coded as 31), *diagram (a) represents the entropy change of the seawater when it freezes* (coded as 32), $\Delta S = q / T$ or $\Delta S = \Delta H_{freezing} / T_{freezing}$ (coded as 33) and *when the seawater freezes the magnitude of the entropy change of the surroundings is bigger than that of pure water freezing* (coded as 34). Among the partial understandings the idea coded as 32 was most common.

This question revealed three misunderstandings related to the specific chemical idea tested in the question. The number of misunderstandings showed an increase in the post-test (almost one quarter) compared to the pre-test (less than 10%). Some 10% of the students argued that *diagram (b) represents the entropy change of the seawater when it freezes* (coded as 41). Another 10% argued that *the entropy change of the surroundings is the same on both occasions* (coded as 42) and finally 9% of the post-test responses showed the misunderstanding that *the magnitude of the entropy change of the surroundings is bigger when pure water freezes than when seawater freezes* (coded as 43). There was not a significant number of misunderstandings relating to general chemical/scientific knowledge. However some misunderstandings occurred in less than 5% of the responses. These are:

- *Entropy is disorder*
- *The enthalpy change of the process of freezing of the seawater is bigger than that of pure water*
- *Entropy increases when the temperature decreases*

- *When the seawater freezes the entropy change of the surrounding becomes bigger than -22.00 J/K mol*
- *Boiling point of seawater is less than that of pure water*
- *Seawater freezes more easily than pure water*

There was a significant improvement in the number of responses which demonstrated a sound understanding in the post-test compared to the pre-test. 9% of the pre-test responses for **(a)** and 13% for **(b)** showed a sound understanding, while these numbers increased dramatically to 48% for **(a)** and stayed almost unchanged for **(b)** in the post-test. These misunderstandings are discussed in detail below.

6.1.1 Diagram (b) represents the entropy change of the seawater when it freezes (41)

This particular misunderstanding was observed in less than 5% of the pre-test responses and 9% of the post-test responses. Respondents argued that diagram **(b)** represents the entropy change of the seawater when it freezes. In diagram **(b)** the magnitude of the change of entropy shown is less than in diagram **(a)**. In fact the magnitude of the change of entropy in the case of freezing seawater is bigger than that of pure water, therefore diagram **(a)** represents the entropy change of freezing seawater. Seawater contains a number of dissolved particles and therefore has a higher entropy value than that of pure water. In this question, it is assumed that ΔH and ΔS do not vary with temperature, although they do vary a little bit. When they freeze, both produce pure ice and the energy released will be the same (as it is given in the question) as when molecules fit together to form a lattice in ice crystal. However, ΔS for the system will vary because the entropy of seawater is greater than the entropy of pure water because of the dissolved ions in it. There are more ways of arranging water molecules and the ions in the seawater than in pure water in which there are only water molecules. Some quotations from the responses are given below:

> *It is diagram (b), because seawater freezes easily and ΔS becomes small ($OT_2/E/S_{13}$).*

> *Diagram (b) belongs to the seawater, because seawater freezes at low temperatures. Therefore entropy change must be less...($ST_2/B/S_{23}$).*

As seen from the students' comments, they thought that if seawater freezes at low temperatures it must have a lower entropy value. Here students perhaps thought only about the value of entropy at low temperatures, although in the question the change of entropy accompanying the freezing process had been asked for. In the first quotation, the respondent actually demonstrates another misunderstanding by arguing that seawater freezes easily. This misunderstanding may have led the respondent into the misunderstanding that seawater has a lower entropy because it freezes easily. It seems that there is a sequence of misunderstanding which leads from one to another.

6.1.2 Entropy change of the surroundings is the same on both occasions (42)

This misunderstanding was identified only in fewer than 5% of the pre-test responses and 6% of the post-test responses. It was argued that entropy change of the surroundings should be the same when seawater and pure water freeze. The reason given was that the change in energy is same when both seawater and pure water freeze therefore the change in the entropy of the surroundings should be the same, as the quoted below shows:

> *The entropy change of the surroundings is the same in both cases, because the same*

> *amount of energy exchange occurs in both cases. I mean, the same amount of heat exchange happens with the surroundings* (OT_2/E/S_{10}).
>
> *The same amount of energy is released to the surroundings in both cases. Therefore the same amount of entropy change occurs in the surroundings* (OT_2/B/S_{14}).
>
> *Since the freezing enthalpies are the same the entropy change of the surroundings should be the same* (ST_2/B/S_9).

Students approached the problem from the energy change point of view but did not consider that the changes in a system are accompanied by changes in the surroundings. The magnitude of the change in entropy is related to the change in the system because freezing of water (or seawater) is a spontaneous process and produces a positive increase in entropy of the universe. The magnitude of the entropy change in the surroundings when seawater freezes is greater than when pure water freezes. There is a larger positive entropy change in the surroundings when seawater freezes because there is a larger negative entropy change in the system because of the dissolved minerals contained in it. These particles increase the possible number of micro states which increases the entropy of the system. Students may have reached this conclusion from the equation that $\Delta S = \Delta H / T$ without appreciating that during freezing the value of T in the equation decreases. Since seawater freezes at lower temperatures than pure water the lower value of T in the equation means that the value of ΔS is bigger as ΔH is assumed not to be changed. This is a another example of the inappropriate use of an equation.

6.1.3 The magnitude of the entropy change of the surroundings is bigger when pure water freezes than when seawater freezes (43)

Some 9% of the post-test respondents demonstrated this misunderstanding. They argued that there must be a greater change in the entropy of the surroundings when pure water freezes compared to when seawater freezes.

> *When seawater freezes the change of entropy is bigger than the entropy change when pure water freezes. In both cases entropy of the system decrease. The entropy of the seawater decreases less than that of pure water. The entropy of the surrounding increases less when seawater freezes compared the entropy increase of the surroundings when pure water freezes* ($ST_2/E/S_{10}$).

As can be seen from the quotation, no reason for the statement was given. It can be speculated that this misunderstanding may be due to the students' lack of knowledge of the relationship between the system and its surroundings. The result suggests that students find difficulty in grasping changes which happen in the system and its surroundings.

6.1.4 Discussion

The question, *Seawater*, generated a lower number of misunderstandings due perhaps to the unfamiliar nature of the question. The high number of blank responses indicates that students did not adequately understand the entropy change of the system and surroundings. The responses showed variation in pre and post-tests. In the pre-test most of the respondents used the definition that entropy is a measure of disorder, which led into definitions that included more mathematical explanations and equations such as $\Delta S = q / T$ and $\Delta S = \Delta H / T$. None of the respondents mentioned the microstates and the ways of arranging the energy in a system which increases the entropy of the system. In addition, responses in the post-test showed more interpretations related to the equations of entropy. Some of the respondents reached the result by interpreting the equations and using mathematical knowledge instead of conceptual understandings. This is important because using mathematical equations to answer a question which tests conceptual understanding is not always possible, especially if the concept has not been understood properly. Similar misinterpretations have been identified in previous chapters. This question once again showed that students are more likely to prefer algebraic solutions to discussions which require conceptual understanding.

6.2 Mixing of Gases

The question, *Mixing of Gases*, tests students' understandings of changes in entropy, enthalpy and Gibbs energy when gases are mixed. It is a joint question which tests ideas from three different areas in each sub-question. However, the main idea tested in the question was that entropy is *the measure of the number of ways that energy can be shared among the particles*. Entropy increases if the number of ways of distributing the available energy among the particles increases and also if the number of ways of arranging the particles in space increases. The other sub-questions test the students' ability to apply the same idea to different cases.

Entropy increases when gases mix because the number of ways of arranging the particles in space increases and this causes an increase in the number of possible microsystems. However, since the temperature of the system is constant, no change occurs in the enthalpy of gases. The mixing process occurs spontaneously that means that Gibbs energy is also negative. All spontaneous processes are accompanied by a decrease in Gibbs energy under constant pressure and temperature. Table 6.2 shows the results.

Table 6.2 Analysis of the students' responses to ***Mixing of Gases***

Code	Description	Pre-test (n=45)						Post-test(n=44)					
		a		b		c		a		b		c	
		f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
00	**Blank**	12	27	21	47	33	73	15	34	19	43	22	50
10	**Uncodeable**	1	-	-	-	2	-	-	-	1	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	3	6	1	-	1	-	3	6	2	-	-	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	15	33	-	-	-	-	15	33	6	14	-	-
31	Entropy increases because disorder of the system increases	5	11	-	-	-	-	6	14	-	-	-	-
32	Entropy is a measure of disorder	3	6	-	-	-	-	1	-	-	-	-	-
33	Entropy increases because available volume increases	7	16	-	-	-	-	8	18	-	-	-	-
34	Enthalpy of the gases does not change	-	-	-	-	-	-	-	-	6	14	-	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	10	22	13	29	9	20	7	16	10	23	9	20
41	Inaccurately connecting the entropy increase to the energy change	3	6	-	-	-	-	1	-	-	-	-	-
42	Entropy increases because of increase of collision of particles	4	9	-	-	-	-	4	9	-	-	-	-
43	Entropy increases because of increase of intermolecular interaction	3	6	-	-	-	-	2	-	-	-	-	-
44	Enthalpy does not change because there is no reaction happening	-	-	7	16	-	-	-	-	5	11	-	-
45	Enthalpy increases	-	-	6	14	-	-	-	-	5	11	-	-
46	Gibbs Energy increases	-	-	-	-	7	16	-	-	-	-	5	11
47	Gibbs Energy does not change	-	-	-	-	2	-	-	-	-	-	4	9
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-	-	-	-	-	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	2	-	8	18	-	-	1	-	4	9	13	30

Table 6.2 shows that the number of blank responses was high in the pre-test compared to the post-test. About one third of the respondents left sub-question (a) blank. However nearly half of the responses for sub-question (b) were blank

in both the pre and post-tests. In addition, three quarters of the respondents left sub-question (c) blank in the pre-test, while half of the responses were blank in the post-test. This high number of blank responses indicates that students did not feel they had enough knowledge of Gibbs energy to answer the question. However the number of blank responses dropped by 25% after the students had been taught, but the remaining high percentage of blank responses suggests that students did not grasp the idea adequately. Less than 5% of the responses were uncodeable and a few of the responses showed no understanding.

33% of the pre and the post-test responses included partial understandings for sub-question (a) and 14% of the post-test responses included partial understandings for sub-question (b). The partial understandings were: *entropy increases because disorder of the system increases* (coded as 31), *entropy is a measure of disorder* (coded as 32), *entropy increases because available volume increases* (coded as 33) and *enthalpy of the gases does not change* (coded as 34).

The number of misunderstandings identified in the responses for sub-question (a) in the post-test was considerably less (16%) when compared with the pre-test responses (22%). In addition, 29% of the pre-test responses for sub-question (b) included some misunderstandings but this figure dropped to 23% in the post-test. Finally, 20% of both the pre-test and the post-test responses for sub-question (c) demonstrated misunderstandings.

The misunderstandings identified were grouped under seven headings.

Inaccurately connecting the entropy increase to the energy change (coded as 41) was identified in 6% of the pre-test responses. 9% of the respondents in both pre and post-test argued that *entropy increases because of increase of collision of particles* (coded as 42). Apart from these, 6% of the responses displayed the misunderstanding that *entropy increases because of increase of intermolecular interactions* (coded as 43). In relation to sub-question (b), 16% of the students in the pre-test and 11% in the post-test demonstrated the misunderstanding that *enthalpy does not change because there is no reaction happening* (coded as 44). The misunderstanding that *enthalpy increases* (coded as 45) was identified in 14% of the pre-test and 11% of post test responses. The final two misunderstandings related to sub-question (c). *Gibbs energy increases* (coded as 46) was detected in 16% of the pre-test and 11% of the post-test responses and the misunderstanding that *Gibbs energy does not change* (coded as 47) was identified in 9% of the post-test responses. There were no significant misunderstandings relating to general chemical/scientific knowledge. However there were some misunderstandings that appeared in less than 5% of the responses:

- *Entropy is disorder*
- *Entropy increases because of increase of kinetic energy*
- *Entropy increases because of increase of number of moles of gases*
- *Entropy increases because of work done*
- *Entropy increases because the gases do not react*
- *Entropy and pressure are conversely proportional*
- *Enthalpy of the gases decreases*

Less than 5% of the pre-test and the post-test responses for sub-question (a) showed sound understanding of the specific chemical idea tested in the question. With respect to sub-question (b), the number of responses which showed sound understanding declined from 18% in the pre-test to 9% at the post test. None of the responses in the pre-test for sub-question (c) showed sound understanding, while 30% of the post-test responses demonstrated sound understanding of the specific chemical idea tested in the question. This seems a significant improvement, but when the number of blank responses is considered, it was apparent that students found Gibbs energy a difficult idea to understand.

6.2.1 Inaccurately connecting the entropy increase to the energy change (41)

This particular misunderstanding was identified in 6% of the pre-test and less than 5% of the post-test responses. Some of the respondents inaccurately related the entropy increase to the energy change of the system. Some of the respondents argued that the energy of the system increases:

> *Since the gases do not react when they are mixed the energy of the system should increase. If energy increases it increases the disorder of the system, and so entropy of the system increases (OT$_2$/B/S$_3$).*
>
> *The enthalpies of both gases are different. When mixed their enthalpies combine, and so entropy of the system increases (OT$_2$/E/S$_{11}$).*
>
> *Since the volume of the gases are doubled, their enthalpy of them increases and entropy increases (ST$_2$/E/S$_3$).*

The enthalpy of the system does not change since the system is kept under constant pressure and temperature. From the above arguments it seems that students believe that the enthalpy change of the system increases due to the mixing of gases. In addition, students confused the enthalpy change with the total energy of the system. Enthalpy was seen as similar to the total energy of the system. The misunderstanding that entropy increases with increasing enthalpy may come from the conventional approach that high energy means instability. As students seemed to understand disorder as instability, chaos or randomness, for them instability may indicate high entropy.

On the other hand, some of the respondents argued that the energy of the system decreases as quoted below.

> *...if the volume increases energy decreases. Systems tend to minimise energy. If the energy decreases entropy increases. This is the reason why entropy of the system increases ($OT_2/B/S_4$).*

Here the respondent seems to confuse the generalisations that systems tend to minimise their energy and maximise the entropy of the universe. Since it was stated in the question that the entropy of the system increases, the respondent thought that the energy of the system should decrease to compensate for the change in the system. This thought trend also appeared during interviews.

> *R: Can you tell me what the second law of thermodynamics says?*
>
> *I: Second law...emm... I think the entropy of the universe increases...it must be something like this...emm. Oh yes, in a spontaneous reaction entropy of the universe increases. Because, to be spontaneous entropy should increase. Because systems always tend to go towards maximum disorder, minimum energy in chemical reactions. Therefore, when disorder increases enthalpy decreases ($SI/B/S_1$).*

Consequently, these results show that students' misunderstandings of entropy seem to relate to the misunderstandings about enthalpy and energy of a system. There is a close connection between the misunderstandings about enthalpy and entropy.

6.2.2 Entropy increases because of increase of collision of particles (42)

Almost one in ten of the respondents had this misunderstanding both in pre and post-tests and seemed to confuse the word 'disorder'. It was perceived as something akin to chaos, randomness or instability. Disorder was also understood as something like movement or fast movement. The word 'disorder' itself seemed to cause misunderstandings because students indicated random or fast movement as well as more collisions when they used the term 'disorder'. It was argued that if the gases are mixed the number of collisions increases among the gas particles, therefore the entropy of the system increases. The quotations illustrate students' thoughts:

> *When the tap is opened the volume of the gases doubled... since the gases do not react with each other, they will only collide with themselves and the walls of the container and their disorder will increase. If disorder increases their entropy increases as well (ST$_2$/B/S$_{17}$).*
>
> *Increase of entropy means increase of disorder... I mean, increase of entropy is the result of increase of disorder by collisions of gas molecules (OT$_2$/E/S$_{12}$).*
>
> *When the gases are mixed, they will do collisions among them. As a result, disorder of the system increases and entropy increases (OT$_2$/B/S$_1$).*

This misunderstanding had been identified previously by Selepe and Bradley (1997), Ribeiro (1992) and Johnstone *et al* (1977). The majority of the responses showed that students believe that disorder is the movement or collisions of the particles. The evidence from interviews also supports this line of thinking.

> *R: Can you explain a little bit more what you mean by disorder?*
>
> *I: The random movement of particles, I mean they don't move in an order... In addition, there might be a lot of collisions among them. If there is such a chaos among the particles, we talk about disorder in this case (SI/B/S$_1$).*

It is clear from this misunderstanding that students' understandings of disorder and its meaning in thermodynamics are different. Students seemed to equate the increase in entropy with the collisions and fast movement of the particles. On this point, it is also possible to confuse kinetic energy and entropy.

6.2.3 Entropy increases because of increase of intermolecular interactions (43)

In this misunderstanding about 10% of the respondents attributed the entropy increase to the intermolecular interaction between the gas particles. The quotations below reflect the students' ideas.

> *Since the gases are different the attraction forces between them will be different, therefore disorder increases...*($OT_2/E/S_{15}$).
>
> *Entropy is the measure of disorder... when the gases are mixed due to intermolecular interactions among the gas molecules entropy increases* ($OT_2/B/S_{17}$).
>
> *During the mixing of Ar and* N_2 *gases due to friction of gas particles and movement entropy increases* ($OT_2/E/S_{17}$).

Students perceive intermolecular interactions such as attraction, repulsion and friction as a source of increase of entropy. They perhaps believe that if particles attract each other this causes an increase of disorder and therefore entropy increases. Once again, the meaning of disorder and change of disorder varies from student to student and there is no common conception of disorder amongst the students. This is most probably due to the meaning of disorder in everyday life where it means randomness or chaos. Hence students related the word to its everyday meaning. The difference between scientific language and everyday language causes misunderstanding of scientific concepts.

6.2.4 Enthalpy does not change because there is no reaction happening (44)

This was a widespread misunderstanding among the responses given to sub-question (b) including 16% of responses in the pre-test and 11% in the post-test. The respondents argued that since the gases do not react with each other there should not be an enthalpy change. In fact enthalpy change is zero, but it is due to the system being kept under constant temperature not due to the fact that no reaction takes place in the mixing process. Students believe that enthalpy only changes if a reaction happens as illustrated below:

> *Enthalpy is the heat given out when a reaction occurs. Since no reaction happens in the system, there is no heat released* $(ST_2/E/S_{11})$.

Some of the respondents stated that enthalpy does not change because there is no reaction, but they did not give any explanation.

Some of the students related the enthalpy change to the ideal behaviour of the gases as quoted below.

> *If the gases do not react there is no enthalpy change. If the gases behave like ideal gases* $\Delta H = 0$ $(ST_2/B/S_{14})$.

It can be seen that the respondents believe that an enthalpy change only happens when a chemical reaction occurs. This misunderstanding may be due to the definition of enthalpy used in textbooks which relates it to chemical reactions. In fact enthalpy change occurs as a result of physical changes such as mixing or phase changes.

6.2.5 Enthalpy increases (45)

This particular misunderstanding was identified in 14% of the pre-test and 11% of the post-test responses. Students' reasoning fell into four categories. The first group of respondents argued that the enthalpy of the system increases because of increasing movement, friction and kinetic energy of the gases after mixing. This kind of approach is illustrated in the quotation below.

> *At the beginning both gases, Ar and* N_2*, were in the volume V and their energy was less since their movements were constrained. When the volume increases their movements increase and energy increases* $(OT_2/B/S_{14})$.

Here, the enthalpy change and total energy of the system seem to be confused. The students believe that an increase in the volume increases the velocity of the particles. In fact the velocity of the particles increases with temperature increase.

The second group of respondents argued that the total enthalpy increases because the enthalpy of both gases adds when they are mixed. Here students again seemed to be confusing enthalpy change and enthalpy which may be due to the fact that enthalpy changes can be added as stated in Hess's Law.

Thirdly, it was argued that enthalpy and volume are directly proportional as shown in the quotation below:

> *Since volume and enthalpy are directly proportional enthalpy increases (ST_2/B/S_{13}).*

Finally, some of the respondents argued that if entropy increases and temperature does not change therefore enthalpy should increase. This is, perhaps, due to the misinterpretation of the equation of entropy, $\Delta S = \Delta H / T$.

6.2.6 Gibbs energy increases (46)

This misunderstanding was identified in 16% of the pre-test and 11% of the post-test responses. Students reasoned their answer in three ways. The majority of the respondents argued that since entropy increases, Gibbs energy should also increase.

> *Gibbs energy change depends on the enthalpy and entropy change. As a result of increase of entropy Gibbs energy increases. $\Delta G = \Delta H - T\,\Delta S$ (OT_2/E/S_5).*

This group of respondents did not understand the relationship between Gibbs energy, enthalpy and entropy. According to the equation, $\Delta G = \Delta H - T\,\Delta S$, an increase in entropy decreases the value of Gibbs energy which means that if entropy increases in a system it favours its spontaneity, but it should be remembered that total change of entropy for the system and the surroundings should be considered.

Some of the respondents stated that no reaction occurs therefore Gibbs energy should increase. There was no explanation as to why they thought this to be the case. Finally, some of them argued that Gibbs energy increases because of the increase of volume.

> *$dG = [\partial P / \partial T]_V = 0$, Gibbs energy change of the ideal gases at constant volume is zero. Since the volume of the gases increases Gibbs energy increases ($OT_2/E/S_5$).*

6.2.7 Gibbs energy does not change (47)

This particular misunderstanding was identified in 9% of the post-test responses and in less than 5% of the pre-test responses. Respondents argued that since the pressure and temperature were constant, Gibbs energy does not change.

> *Since pressure was constant Gibbs energy change is zero ($OT_2/E/S_4$).*
>
> *It does not change because pressure and temperature are constant ($ST_2/E/S_4$).*

Others argued that Gibbs energy does not change because the enthalpy is constant. All these responses demonstrate a poor understanding of Gibbs energy. The fact is that if the Gibbs energy change is negative then the process occurs spontaneously at constant pressure and temperature.

6.2.8 Discussion

The question, *Mixing of Gases*, revealed a number of misunderstandings about entropy, enthalpy and Gibbs energy change. More than half of the responses were blank which indicates that students did not have the knowledge required to answer the question relating to Gibbs energy. Overall, the responses showed more understanding in the post-test compared to the pre-test.

Among the responses which related to the entropy, the biggest misunderstanding was about the use of the term 'disorder' where the majority of the respondents showed different interpretations such as chaos or randomness. Almost all of the students defined entropy as a measure of disorder. However they did not appear to adequately understand the definition of 'disorder' as the majority of them failed to answer the question. The following discussion occurred during a pre-interview and illustrates this:

> *R: Can you tell me what you knew about entropy when you came to this class?*
>
> *I: I only know that the word means disorder... (long silence)*
>
> *R: Can you tell me what you mean by disorder?*
>
> *I: Now I remember what our lecturer told us when we were in first year...(long silence) I remember something but it is difficult to explain it...(long silence).*
>
> *R: So do you remember what changes the entropy of a substance?*
>
> *I: Temperature changes...emm*
>
> *R: Can you tell me little bit more about how temperature changes entropy?*
>
> *I: For example, temperature increases the velocity of molecules. Once the velocity increases movements increase. For instance, think about when students sit in a class and when students start moving around in the class. In this case entropy increases because disorder increases (OI/B/S_1).*

Almost all of the interviewees started with this kind of definition when they were asked about entropy. It is appeared that they mean macrophysical disorder or visual disorder by the term 'disorder' which most likely originated from using inappropriate models to illuminate the entropy idea or disorder at school as suggested by the following discussion:

> *R: You just mentioned disorder. Can you tell me what you mean by disorder?*
>
> *I: I mean, for example our teacher explained when we were in first year. Think about a class having 50 students in. If we put another 50 students into this class and all of them moving around. There will be a big disorder, but if all of them sit there will be order. Disorder can be explained like this. I mean, disorder is the random movement of molecules (SI/B/S_2).*

It is apparent that the analogy used by teachers resulted in the student misunderstanding entropy or disorder. It suggests that instructors should be careful when using analogies from macrophysical world to the microphysical world as they may cause confusion.

In the questionnaires only two of the respondents mentioned microstates which are the possible ways of arranging of the particles. As they only focussed on the definition of entropy as a measure of disorder, in many cases they failed to reason why the entropy increases when gases are mixed. Students linked entropy to disorder only very loosely and this demonstrates that it is important to focus on how students understand 'disorder'.

The results showed that a significant proportion of the students thought that entropy increases when particles move faster or collide with each other. Ribeiro (1992) also reported that students considered the disorder of the system increases if the kinetic energy of the particles (movement) increases. There was evidence that students also confuse entropy and kinetic energy.

> *R: In your opinion what changes the entropy?*
>
> *I: Temperature can change?*
>
> *R: Can you tell me little bit more. How does it change the entropy?*

> *I: For example...emm...if we think about gases, when we increase the temperature of gases their entropy increases.*
>
> *R: Why is that do you think?*
>
> *I: Because their velocity increases, their kinetic energy increases...*
>
> *R: So do you think there is a correlation between kinetic energy and entropy?*
>
> *I: ...(long silence)...emm it must be. I mean in gases it must be but I don't know more about this issue (OI/B/S_3).*

In addition, as entropy is closely related to disorder, some of the students also confused disorder with the intermolecular interactions between particles, such as attraction and repulsion. They thought that if the number of intermolecular interactions increases disorder increases therefore entropy increases.

With respect to enthalpy, the major misunderstanding among the students was that enthalpy only changes if a chemical reaction occurs. This misunderstanding may originate from the definition of enthalpy which is energy released as heat when a reaction occurs under constant pressure. Gibbs energy was also misunderstood and there was a belief that it increases if enthalpy and entropy increase or it does not change if no reaction occurs.

6.3 Spontaneous Change

This question dealt with the fact that in a spontaneous change the entropy of the universe increases. *Spontaneous Change* suggests that visual disorganisation and entropy are not synonymous ideas and the number of equivalent arrangements of microstates should also be considered. If it is entirely considered from the visual disorder point of view, it is not always possible to explain situations such as the one in this question. There are two competing factors in this case;

there is an apparent increase in organisation when crystallisation occurs which reduces the entropy. Secondly, since the system is thermally insulated, the temperature of the system increases during freezing because of the formation of new intra-molecular bonds (such as H-bonds) in the ice crystals. This temperature increase makes a greater spectrum of thermal microstates available, and therefore the entropy increases and also the process occurs spontaneously. The students' responses are summarised in Table 6.3.

Table 6.3 Analysis of the students' responses to ***Spontaneous Change***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	**Blank**	25	54	14	30
10	**Uncodeable**	-	-	2	-
20	**No understanding of the specific chemical idea tested in the question**	2	-	3	6
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	9	20	4	9
31	Entropy increases if disorder increases	3	6	1	-
32	Entropy of the system increases	6	13	3	6
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	15	33	21	45
41	Entropy of the system decreases	12	26	19	40
42	Entropy of the system does not change	3	6	2	-
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	-	-	5	11

Table 6.3 shows that more than half of the responses in the pre-test were blank and this dropped to 30% in the post-test. Only two of the post-test responses were uncodeable and less than 5% of the pre-test and 6% of the post-test responses demonstrated no understanding.

The responses showed partial understandings which broadly fell into two categories. Some of the students mentioned that *entropy increases if disorder increases* (coded as 31) and a significant percentage of the respondents also mentioned that *the entropy of the system increases* (coded as 32) but they did not provide an explanation of this answer.

Students' misunderstandings were broadly grouped under two headings. These are that *the entropy of the system increases* (coded as 41) which was identified in 26% of the pre-test and 40% of the post-test responses. Only 6% of the pre-test responses and less than 5% of the post-test responses included the misunderstanding that *entropy of the system does not change* (coded as 42). No misunderstandings were identified relating to general chemical/scientific knowledge. In addition, a number of misunderstandings were identified with low frequencies:

- *Entropy is disorder*
- *When crystallisation occurs disorder increases*

No response demonstrated a sound understanding in the pre-test but 11% of the post-test responses displayed sound understanding of the chemical idea tested in the question.

6.3.1 Entropy of the system decreases (41)

This was a common misunderstanding identified in 26% of the pre-test and 40% of the post-test responses. The increase in the percentage in the post-test can be attributed to the increase in the number of respondents who attempted to answer the question. In the pre-test, 54% of the responses were blank but this figure dropped to 30% in the post-test. As the response rate increases, the probability of misunderstandings also increases. The responses were dominated by the argument that as the system becomes less disordered the entropy decreases. Students only considered the visual disorder of the system as illustrated below.

> *After the crystallisation entropy of the system, the disorder starts to decrease. In a crystal ions can only make ordered and directed movements, this reduces entropy (*$OT_1/B/S_{12}$*).*
>
> *Entropy decreases. The more free movement of molecules the more entropy. When the molecules change from gas phase to solid phase their entropy decreases (*$ST_1/B/S_7$*).*
>
> *The entropy of the system decreases because matter turns to solid from liquid (*$OT_1/E/S_{17}$*).*

As already identified, visual disorganisation and entropy are not synonymous ideas and the number of equivalent arrangements of microstates should be considered. If entropy is considered from the visual disorder point of view alone, it is not always possible to explain situations as in this question. A few of the students mentioned microstates and the second law of thermodynamics, which states that entropy of the universe increases in a spontaneous change. Students did not consider the application of the second law of thermodynamics and spontaneity. These findings suggest that entropy should be taught in connection with microstates or from the perspective of possible arrangements of ways of distributing of energy. Disorder should be explicit as each student visualises it in a different way, leading to the potential for different interpretations and misunderstandings.

6.3.2 Entropy of the system does not change (42)

This misunderstanding was identified only in 6% of the pre-test and less than 5%

of the post-test responses. It was argued that since the system was thermally insulated there should not be any change in the entropy of the system as illustrated below:

> *Entropy does not change because the system is thermally insulated (OT_f/E/S_{18}).*
>
> *Entropy only changes with temperature (ST_f/E/S_8).*
>
> *As the system is thermally insulated any change in entropy should not be considered (ST_f/E/S_{15}).*

The respondents believed that if the system is thermally insulated there is no entropy change because as one of them stated entropy only changes with temperature. Overall the responses showed that students' understanding of entropy is not clear and consists largely of memorisation of the facts without understanding of the underlying principles.

6.3.3 Discussion

This question tested students' understanding of the entropy change of a process which occurs in natural or everyday phenomena. The reaction was irreversible and the overall change of entropy of the universe was positive. Students' responses showed that the majority of them looked at visual organisation of the system instead of the second law of thermodynamics. It demonstrated that the visual concept of randomisation is difficult to apply, and also that visual disorganisation and entropy are not synonymous. Although highly regular crystals have been formed, the spontaneity of the process requires increased entropy (Warn 1988, p.61). The number of equivalent arrangements of microstates must be higher after the crystallisation because, as the system was insulated, the temperature of the system increased causing an increase in the possible number of microstates. It is misleading to interpret entropy simply as 'mixed-upness'. From the students' responses, it was apparent that they perceived entropy as disorder or mixed-upness of the system. As discussed in previous sections of this chapter, the students' understanding of 'disorder' should be clarified during teaching of entropy.

6.4 Carbon Dioxide and Propane

Carbon Dioxide and Propane tests the students' understanding of the fact that substances have higher entropies if they contain heavier atoms and a large number of atoms in each molecule. Since propane (C_3H_8) has more atoms than carbon dioxide (CO_2) in its moleculeand they are more branched out in propane, propane has a greater entropy than carbon dioxide. The spreading of atoms in molecule causes an increase in the number of ways in which energy can be shared among the atoms and also increases the number of microstates. Students' responses were analysed and summarised in Table 6.4.

Table 6.4 shows that a significant proportion of the responses were blank, 39% in the pre-test and 34% in the post-test Only one of the responses in the post-test was uncodeable. In addition, 6% of the pre-test and only one of the post-test responses demonstrated no understanding. One in five of the pre-test responses and 13% of the post-test responses included partial understandings. These are *entropy is a measure of disorder* (31) and *entropy value of propane is bigger than that of carbon dioxide* (coded as 32). Most of the partial understandings were composed of a listing of the facts about entropy. Students avoided discussions about the idea which can be seen as a sign of a lack of understanding.

Table 6.4 Analysis of the students' responses to ***Carbon Dioxide and Propane***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	**Blank**	18	39	16	34
10	**Uncodeable**	-	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	3	6	1	-
30	**Understanding of only some aspect/s of the specific chemical ideatested in the question**	10	22	6	13
31	Entropy is a measure of disorder	3	6	1	-
32	The entropy value of propane is bigger than that of carbon dioxide	7	15	5	11
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	11	24	18	38
41	Entropy value of carbon dioxide is bigger than that of propane	8	17	4	9
42	Entropy of both gases are the same	3	6	14	30
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	5	11	6	13

Two misunderstandings were identified in significant percentages. 17% of the pre-test and 9% of the post-test responses included the misunderstanding that *entropy value of carbon dioxide is bigger than that of propane* (coded as 41). The second was that *entropy of both gases is the same* (coded as 42) and was identified in 6% of the pre-test responses but its percentage sharply increased to 30% in the post-test. Some other misunderstandings which were not included in the table are listed below:

- *Entropy is the measure of instability*
- *Molecular weight of substances does not affect the entropy*
- *Confusion of atom and molecule*
- *The temperature of the flasks are the same because they are identical*

Finally, 5% of the pre-test and 6% of the post-test responses showed sound understanding. The misunderstandings which were identified will be discussed in the following sections.

6.4.1 Entropy value of carbon dioxide is bigger than that of propane (41)

This misunderstanding was identified in 17% of the pre-test responses and dropped to 9% in the post-test responses. The responses showed a number of different arguments for why carbon dioxide has a bigger entropy than propane.

> *Entropy of propane is less, because it has more particles (means atoms) in one molecule, in connection with its structure it has less area to move. Since CO_2 has fewer particles(means atoms) in it, it has less molecular volume. Therefore it has more space to move, and its disorder is bigger. As a result, carbon dioxide has more entropy than propane (OT_1/B/S_8).*
>
> *Entropy is disorder. A CO_2 molecule contains 3 atoms, but there are 11 atoms in one C_3H_8 molecule. Therefore, the density of gases in the second flask (propane) is more than the first flask (carbon dioxide). Thus carbon dioxide molecules can move easily and its entropy is bigger (OT_1/B/S_4).*

The majority argued that carbon dioxide molecules are smaller than propane molecules. If the same number of molecules are put into the same volume, the molecules which have less molecular volume must occupy less space and therefore must have more free space in which to move. Consequently the entropy of carbon dioxide is greater than propane. There are a number of misunderstandings in this kind of approach. Firstly, students' understanding of kinetic molecular theory of the gases is limited. Gases cannot be thought of in the same way as liquids and solids. Gases are assumed to be 'point like' particles according to Kinetic Molecular Theory where their specific volumes can be neglected. Secondly, as discussed in section 6.2, students confuse entropy and movement. They believe that the more movement means more entropy. This misunderstanding has a connection with the misunderstandings about Kinetic

Molecular Theory and may be a linked to the confusion of kinetic energy and entropy.

Some of the respondents argued that carbon dioxide has a bigger entropy value than propane because the 'O' atom in the molecule has unpaired electrons and they cause repulsive forces between the molecules. Thus the molecules will interact with each other and the disorder will increase leading to an increase in entropy. Similar misunderstandings were also identified in the responses given to the question *Mixing of Gases* discussed in section 6.2. Students' statements during the interviews followed the same pattern as can be seen from the following dialogue:

> *R: You say that carbon dioxide has bigger entropy value than that of propane at the same temperature. Can you tell me why?*
>
> *I: Both of them have the same molecular weight, and their temperatures are the same, aren't they? In this case the only difference is their molecular structure. Propane molecules are bigger than carbon dioxide molecules. Therefore propane molecules collide with each other and they cannot move freely. But, carbon dioxide molecules can move more freely and quickly. This increases the disorder. Therefore carbon dioxide has more entropy (SI/E/S_9).*

A small number of respondents seemed to confuse the meaning of microstates. They thought of microsates as being in a smaller molecular volume perhaps thinking of the meaning of the term 'micro' itself. This group of students argued that since the carbon dioxide molecules are smaller than propane molecules the probability of them being in microstates is greater than for propane molecules, thus they have more entropy. In a post-interview, a student considered the individual atoms in a molecule as a microstate by arguing as follows:

> *R: How do the entropy values of carbon dioxide and propane compare at the same temperature? Both of them have the same molecular weight.*

> *I: I expect to propane to have more entropy.*
>
> *R: Can you tell me why?*
>
> *I: Because, we said that entropy increases with increase of microstates. Here I thought of the particles as microstates. There are more particles (in propane), therefore we can write different open formulas of propane but it is impossible for carbon dioxide... (SI/B/S$_1$).*

These responses indicate that students are aware of microstates but do not have an understanding. Ribeiro (1992) reports similar findings.

6.4.2 Entropy of both gases is the same (42)

This misunderstanding was not common in the pre-test (6%) but identified in 30% of the post-test responses. Two arguments were put forward as to why both gases have same entropy value. One was that since their temperatures are the same, their entropy must be the same. This kind of approach can be seen below:

> *Entropy of these two gases are the same, because their temperatures are the same. Also their mole numbers are the same (ST$_1$/B/S$_{14}$).*
>
> *S = q / T, since the temperatures are constants, their entropy should be the same. Entropy changes with temperature (ST$_1$/B/S$_{22}$).*

It is clear that students only focussed on the temperature of the gases whereas in fact temperature is one of the factors that changes the entropy, but there are others as well. In some of the responses, students argued that since the molecular weights, mole numbers and the volumes are the same, both gases should have the same entropy value. The following quotation represents this kind of approach.

> *The entropy of both gases is the same. Both of them have the same M_A (molecular weight), number of mole and volume. Therefore their entropies are the same (OT$_1$/B/S$_6$).*

This approach was also evident during the interviews:

R: How do entropy values of carbon dioxide and propane compare at the same temperature? Both of them have the same molecular weight.

I: They must be equal? The same temperature, the same molecular weight.

R: Can you tell me why you thought that they must be equal?

I: If we look at the equation, entropy is equal to q / T. If the temperature is the same entropy must be the same (SI/E/S_3).

These responses suggest that students did not fully understand entropy even after the subject has been taught. Generally students were not able to apply their knowledge to problems.

6.4.3 Discussion

This was the last question which tested students' understanding of entropy. As in the previous questions a significant percentage of the students (39% in the pre-test and 34% in the post-test) left the question blank. In this question, the size of the molecules was the main factor determining the entropy. More students focussed on the size of the molecules in the pre-test than in the post-test. Two lines of reasoning were applied. The first of these that carbon dioxide molecules have fewer atoms and they are small compared to propane, therefore they can move more rapidly. In contrast, propane molecules are large so they have little space to move in and hence their entropy is less.

The second was that propane has a higher entropy because it has more atoms than carbon dioxide and more atoms leads to increased movement of the particles. These findings are similar to Selepe and Bradley's (1997) study. Only a few students were able to explain the higher entropy of propane in terms of the greater number of atoms and more branched structure. In other words, in propane the possible number of microstates is higher than that of carbon dioxide. As a result, the movement of particles was perceived as a starting point for the value of entropy. This suggests that students confused entropy and kinetic energy as Selepe and Bradley (1997) argued.

The number of students who argued that entropy of the gases was the same increased in the post-test. They reasoned that the temperature and the molecular weight of the molecules are the same therefore so is the entropy, suggesting that students relate the entropy only to temperature and molecular weight.

6.5 Conclusions

The preceding discussion provides an insight into students' understanding of entropy. The results show that a considerable number of misunderstandings are present both before and after the subject is taught.

Entropy depends on the temperature, volume (in the case of gases), the state of a substance or system and type and amount of substance. Students' written responses and interview results showed that factors affecting entropy were poorly understood or in some cases, not understood at all. Similar to Selepe and Bradley (1997)'s findings, students argued that entropy is equal to the disorder of the system or simply stated that 'entropy is disorder'. The findings indicate that a major difficulty among the undergraduates who took part into this study was the understanding of the term 'disorder'. The term 'disorder' itself seems to be a major source of confusion. Almost all of the respondents defined entropy from the visual disorder point of view indicating chaos, randomness, or instability in some cases.

It is apparent that, in many cases, students rote learned the definition of entropy from textbooks. Further probing on the use of the term 'disorder' revealed that it was used to refer to movement, collision of particles or mixed-upness as in Selepe and Bradley (1997) and Ribeiro (1992). The findings also revealed that visual disorder and entropy were considered as synonymous.

The second important finding was that the questions related to entropy had a relatively lower response in comparison to previous questions related to internal energy and enthalpy. In some cases, the blank response rate was as high as over 50% which suggests that students possibly were unable to answer the questions. The majority of the responses were composed of basic facts or statements on the subject and only a small number of the students attempted to discuss it at the molecular level or give an explanation of their responses. Students tended to use mathematical equations and preferred algebraic solutions.

Thirdly, it appeared that there was a relationship between the misunderstandings identified in this section and those identified in previous sections. For instance, a considerable number of misunderstandings about entropy are possible due to the students' misunderstandings of enthalpy and energy of a system. In addition, some respondents seemed to confuse the kinetic energy of a system and entropy. The majority of the students could not use thermodynamic principles to explain the change in entropy of the system. The students were found to be poor and limited in thinking at a microscopic level. Mostly they considered their answers at a macrophysical level and consequently were unable to provide interpretations at a molecular level. In many cases, everyday meanings of the words dominated students' understandings indicating they are more likely to use an everyday notion of a scientific word than the accepted scientific one.

Chapter 7

Chapter 7

Analysis of The Responses About *Gibbs Energy and Related Ideas*

This chapter reports an analysis of the students' responses to three questions about Gibbs energy and related ideas. These are *Transformation of Diamond to Graphite*, *Two Spontaneous reactions* and *Gibbs Energy*. Each question will be discussed in the following sections.

7.1 Transformation of Diamond to Graphite

This question tests the idea that the magnitude of Gibbs energy indicates how far the reaction is from equilibrium at a given composition, but it provides no information about the rate of reaction (see Appendix 8). Any of the diagrams would be a valid answer since they were not supported with numerical data. ΔG is a thermodynamic value and it provides information about the equilibrium but not about the rate of reaction. There are reactions that have a highly negative ΔG value but occur very slowly and some reactions that occur very quickly but have a very small negative ΔG value. So, ΔG is not a criterion for the rate of reaction and it is a fact that thermodynamic data do not provide any information about the kinetics of a reaction. Table 7.1 summarises students' responses.

Table 7.1 shows that this question did not generate a wide range of responses and 65% of the pre-test and 47% of the post-test responses were blank. In addition, 20% of the pre-test and 36% of the post-test responses demonstrated no understanding of the specific chemical idea tested in the question. No significant

Table 7.1 Analysis of the students' responses to ***Transformation of Diamond to Graphite***

Code	Description	Pre-test (n=46)		Post-test (n=47)	
		f	%	*f*	%
00	Blank	30	65	22	47
10	Uncodeable	-	-	-	-
20	No understanding of the specific chemical idea tested in the question	9	20	17	36
30	Understanding of only some aspect/s of the specific chemical idea tested in the question	-	-	-	-
40	Evidence for misunderstandings relating to the specific chemical idea tested in the question	6	13	8	17
41	The slower the reaction the smaller change in Gibbs energy	3	6	6	13
42	The bigger Gibbs energy change means the faster the reaction occurs	3	6	2	-
50	Evidence for misunderstandings relating to general chemical / scientific knowledge	-	-	-	-
60	Sound understanding of the specific chemical idea tested in the question	-	-	-	-

number of partial understandings were identified and also none of the responses showed sound understanding of the specific chemical idea tested in the question. Two misunderstandings were identified from the students' writings; these are *the slower the reaction the smaller change in Gibbs energy* (coded as 41) which was identified in 6% of the pre-test and 13% of the post-test responses and *the bigger Gibbs energy change means the faster reaction occurs* (coded as 42). This was identified in 6% of the pre-test and less than 5% of the post-test responses. The misunderstandings are discussed in the following sections in detail.

7.1.1 The slower the reaction the smaller change in Gibbs energy (41)

This misunderstanding increased from 6% in the pre-test to 13% in the post-test. This increase can be attributed to the higher response rate. Since more students answered the question the possibility of misunderstandings increase. Students simply argued that since the reaction takes place very slowly, the change in Gibbs energy must be less. Some of the responses quoted below reflect the students' views.

> *Diagram B, because since the transformation of diamond to graphite takes place slowly the change in Gibbs energy must be less (ST$_f$/E/S$_{16}$).*
>
> *Since the reaction proceeds slowly, Gibbs energy change must be negative and close to zero. Therefore the answer is B (ST$_f$/E/S$_{11}$).*
>
> *Diagram B represents it, because Gibbs energy change must be very small as the reaction occurs very slowly (ST$_f$/B/S$_{13}$).*

The respondents believed that there is a relationship between the reaction rate and magnitude of Gibbs energy change. This kind of misunderstanding shows that students cannot differentiate between the kinetics and the thermodynamics of a chemical reaction.

7.1.2 The bigger Gibbs energy change means the faster the reaction occurs (42)

This misunderstanding was identified in 6% of the pre-test and less than 5% of the post-test responses and is a slightly different expression of the previous misunderstanding. Here, the respondents argued that if the Gibbs energy change of a reaction is large, the reaction takes place faster. One respondent's answer is quoted below.

> *The bigger the Gibbs energy change the faster the reaction occurs. Gibbs energy changes must be small for the transformation of diamond to graphite as the reaction occurs very slowly (OT$_f$/E/S$_{11}$).*

The student directly related the magnitude of Gibbs energy to the rate of reaction. This misunderstanding was highlighted by Johnstone *et al* (1977) who reported that one student in four considered that a reaction for which the Gibbs energy change is large occurs rapidly (p.249). It is apparent from the findings of this study that undergraduates in Turkey are also hold the same misunderstanding. The two misunderstandings possibly originated from an analogy from the macrophysical world that the further things fall, the faster they go, or even the more energy provided, the higher the velocity as argued by Johnstone *et al* (1977). Undergraduates seemed to confuse the common sense ideas of physics with chemical thermodynamics (Johnstone *et al* 1977, p.249), due to a poor understanding of Gibbs energy and chemical thermodynamics.

7.1.3 Discussion

Transformation of Diamond to Graphite generated a narrow range of responses as well as revealing important undergraduates' misunderstandings about Gibbs energy and the rate of a reaction. The high number of blank responses indicates that undergraduates have little understanding of this idea. However, in the post-test more respondents tried to answer the question but the same misunderstandings persisted. Misunderstandings seemed to originate from a confusion of physics and chemical thermodynamics.

From the post-interviews students' responses to the question about understanding of the relationship between the magnitude of the Gibbs energy change and reaction rate confirmed the misunderstandings, as illustrated below:

> *R: ... could you tell me, can we make a guess about the rate of a reaction by looking at the magnitude of a reaction Gibbs energy value?*
>
> *I: if... one... If a reactions occurs spontaneously yes... rate of a reaction... I am telling what I think right now.*
>
> *R: OK*
>
> *I: If a reaction does not occur spontaneously, it means, it occurs at low rates.*

R: Can we decide (rate of a reaction) by looking at the Gibbs energy value? Let's say we have two reactions, one has positive Gibbs energy one has negative Gibbs energy. What do you think in this case?

I: At first glance, It seems positive...because it has positive Gibbs energy, it means it occurs more rapidly. The other one must be slower because it has negative Gibbs energy.

R: You are saying that if $\Delta G > 0$ it occurs faster! What about of the case where both of them have negative ΔG. Let's say both reactions have negative ΔG, one of them has -20 KJ/mol and the other one has -40 KJ/mol. In this case which one do you think occurs more rapidly?

I: The one with a bigger magnitude.

R: Which one , 40?

I: No, -20, because it is bigger than -40 mathematically.

R: Why that so?

I: Only because of the mathematical value of them. The bigger value is bigger, and the smaller value is small. I decided according to the mathematical value of them. I don't know any more about Gibbs energy. Mathematically it (means -20) is bigger. (SI/E/S_4)

As can be seen from the beginning of the proceeding discussion, the interviewee was not aware of the spontaneity of a reaction. She argued that if a reaction does not occur spontaneously then it occurs at low rates. She may have had the misunderstanding that spontaneous reactions occur quickly. Selepe and Bradley (1997) argued that students perceived 'spontaneous' as ' immediate or rapid action' and as a result it was thought that slow reactions were not spontaneous. Subsequently the interviewee also showed no understanding of the positive and negative values of Gibbs energy. This is interesting, because at the beginning of the interview she stated facts about Gibbs energy including,

If $\Delta G > 0$ reaction does not occur,
If $\Delta G = 0$ reaction is at equilibrium and,
if $\Delta G < 0$ reaction occurs spontaneously.

This kind of approach suggests that basic facts had been memorised without understanding them and therefore the interviewee did not realise that reactions with a positive Gibbs energy value do not occur as she argued that they occur more rapidly. In another subsequent question (the comparison of two hypothetical reactions with negative Gibbs energy value) the interviewee approached the problem from only the mathematical stand point and did not compare any chemical aspects. She simply compared, mathematically, the magnitudes of Gibbs energy values. It was also admitted that it was a guess, because the interviewee also declared that she did not know any more about Gibbs energy. This kind of thinking perhaps explains the source of the above misunderstandings in that students look at the mathematical value without an understanding of the underlying chemical ideas.

7.2 Two Spontaneous Reactions

Two Spontaneous Reactions tests two ideas. Firstly sub-question (**a**) tests the idea that thermodynamic quantities do not provide any information about the rate of a reaction while secondly sub-question (**b**) tests the idea that a more negative value of Δ_rG indicates that it is more probable the reaction happens, because the more negative the value of Δ_rG^θ , the bigger positive value of the reaction equilibrium constant, K (see Appendix 8). The expected answer for sub-question (**a**) was that these data cannot be used to make a judgement about the relative rates of these reactions, because thermodynamic quantities cannot be used to make a judgement about the kinetics of a reaction. For sub-question (**b**) the following answer was expected. The second reaction would go most fully towards completion. The Δ_rG^θ value is more negative which indicates a bigger value of K which means a bigger concentration of the products than the reactants in the system. Thus, the second reaction goes further towards full completion. The results gathered from the students' writing are summarised in Table 7.2.

Table 7.2 Analysis of the students' responses to ***Two Spontaneous Reactions***

Code	Description	Pre-test (n=45)				Post-test(n=44)			
		a		b		a		b	
		f	%	*f*	%	*f*	%	*f*	%
00	**Blank**	21	47	24	53	13	30	16	36
10	**Uncodeable**	1	-	1	-	2	-	1	-
20	**No understanding of the specific chemical idea tested in the question**	9	20	9	20	4	9	7	16
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	2	-	7	16	5	11	10	23
31	Reaction occurs spontaneously if ΔG (0	2	-	-	-	5	11	-	-
32	The reaction with more negative $\Delta_r G^\theta$ goes towards full completion	-	-	7	16	-	-	10	23
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	11	24	2	-	20	45	8	18
41	The smaller $\Delta_r G^\theta$, the faster the reaction occurs	2	-	-	-	15	34	-	-
42	The bigger $\Delta_r G^\theta$, the faster the reaction occurs	9	20	-	-	5	11	-	-
43	The reaction with bigger $\Delta_r G^\theta$ goes towards full completion	-	-	1	-	-	-	3	6
44	If a reaction occurs fast it goes towards full completion	-	-	1	-	-	-	5	11
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	-	-	1	-	3	6	4	9

Table 7.2 shows us that almost half of the responses for both sub questions in the pre-test were blank, however this number reduced in the post-test. The percentage of blank responses dropped by 17% to 30% for sub-question (a) and to 36% for sub-question (b). A few responses were uncodeable. In addition, a large number of responses demonstrated no understanding of the specific chemical idea tested in the question, including 20% of the pre-test responses for both (a) and (b) dropping to 9% for (a) and 16% for (b) in the post-test. A number

of responses showed partial understandings. While less than 5% of the pre-test responses for (**a**) showed the fact that *reaction occurs spontaneously if* $\Delta G \langle 0$ (coded as 31), this increased to 11% in the post-test. Again 16% of the pre-test responses for (**b**) demonstrated the understanding that *the reaction with more negative* $\Delta_r G^\theta$ *goes towards full completion* (coded as 32), while this increased to 23% in the post-test.

The responses showed four different misunderstandings with significant frequencies. These are *the smaller* $\Delta_r G^\theta$*, the faster the reaction occurs* (coded as 41) which was identified in less than 5% of the pre-test and 34% of the post-test responses. Some of the students argued that *the bigger* $\Delta_r G^\theta$*, the faster the reaction occurs* (coded as 42) which was identified in 20% of the pre-test and 11% of the post-test responses. The misunderstanding that *the reaction with bigger* $\Delta_r G^\theta$ *goes towards full completion* (coded as 43) was identified in 6% of the post-test responses, and finally *if a reaction occurs fast it goes towards full completion* (coded as 44) was identified in 11% of the post-test responses. Some misunderstandings were also identified at less than 5% frequency. These were:

- *Enthalpy change of a spontaneous reaction is negative*
- *Confusion of* ΔG *and* ΔH
- *The rate of a reaction depends only on temperature*
- *If a reaction occurs spontaneously it goes towards full completion*
- *The bigger* $\Delta_r G^\theta$ *the higher the temperature*

Finally, only one response in the pre-test showed sound understanding of the specific chemical idea tested in the question with a little improvement in the post-test. 6% of responses for (a) and 9% of responses for (b) demonstrated sound understanding of the specific chemical idea tested in the question.

7.2.1 The smaller $\Delta_r G^\theta$, the faster the reaction occurs (41)

This particular misunderstanding was widely identified in the post-test responses. 34% of the students argued that the rate of the reaction is directly proportional to the magnitude of the Gibbs energy change by stating that the smaller $\Delta_r G^\theta$, the faster the reaction occurs. Students' answers showed that there is a strong belief, among the undergraduates, that the Gibbs energy change of a reaction gives an indication of the rate of the reaction. Some of the responses are quoted below:

> *We can compare the rate of the reactions. The reaction with small change in Gibbs energy occurs faster... ($OT_2/B/S_1$).*
>
> *To become spontaneous ΔG must be smaller than zero. The smaller Gibbs energy the faster the reaction happens. So, the second reaction occurs faster than the first one ($ST_2/B/S_5$).*

It was not clear why the respondents thought in this way, because they did not give an explanation. However, some of the respondents used their everyday experiences to answer the question as shown below:

> *The second reaction occurs faster. Rusting happens easily. The Gibbs energy change is less and it happens spontaneously ($ST_2/E/S_{10}$).*

Perhaps students' misunderstandings originated from this everyday phenomenon. However, as discussed in section 7.1, students displayed the opposite misunderstanding in response to the question called *Transformation of Diamond to Graphite*. However, here it would be argued that as the rusting of iron is a well known everyday phenomenon, it may play a part in explaining the origin of the misunderstanding.

7.2.2 *The bigger $\Delta_r G^\theta$, the faster the reaction occurs (42)*

This misunderstanding is the converse of the above. However in contrast to the above, this was identified in 20% of the pre-test responses and dropped to 11% in the post-test. Students simply argued that if the Gibbs energy change is bigger, then the reaction occurs faster. Some of the responses are quoted below:

> *The bigger the Gibbs energy the faster the reaction happens* ($OT_2/B/S_{11}$).
>
> *The first reaction occurs fast. Since its $\Delta_r G^\theta$ is big. In addition, transformation from gas to liquid happens faster compared to solid* ($ST_2/B/S_{16}$).
>
> *The Gibbs energy change of first reaction is bigger. Therefore the kinetic energy becomes more, I think, the first reaction occurs faster* ($OT_2/E/S_{12}$).

Students approached the problem from different points of view. Some approached it from a macrophysical point of view as illustrated in the second quotation by considering phase changes. In the first reaction the reactants are in the gaseous phase and the product is in the liquid phase, but in the second reaction the product is in the solid phase. Therefore perhaps they thought that making a solid from the gas must take more time compared to making a liquid from gas reactants. In addition some of them related Gibbs energy to kinetic energy as in the case of the third quotation above. Relating or confusing kinetic energy with enthalpy was observed in the responses which were given to the questions related to entropy. Students seemed to be confused between kinetic energy and entropy. Perhaps they thought about the relationship between Gibbs energy and entropy hence they ended with the above misunderstanding as entropy contributes to Gibbs energy, and so Gibbs energy must have close relationship with kinetic energy according to them. These kinds of responses once again indicate that students' understanding of Gibbs energy is vague and for from the chemical sense.

7.2.3 The reaction with bigger $\Delta_r G^\theta$ goes towards full completion (43)

This particular misunderstanding was identified in the responses given to sub question **(b)**. It was not evident in the pre-test but 6% of the post-test responses contained this misunderstanding. Students simply argued that if the Gibbs energy change of a reaction is larger, it goes towards full completion. One of the respondents explained that if the Gibbs energy change becomes large the reaction occurs rapidly, so it goes towards full completion. This kind of response suggests that students did not adequately understand the reaction kinetics, thermodynamics and chemical equilibrium. This approach will be further discussed under the next heading.

7.2.4 If a reaction occurs fast it goes towards full completion (44)

This final misunderstanding was identified in 11% of the post-test responses and in only one of the pre-test responses. It was argued that if a reaction occurs fast it goes towards full completion.

> *If a reaction happens faster it produces more products and goes toward full completion (ST$_2$/B/S$_9$).*

It seems that students were unaware of reaction kinetics and the equilibrium state. Every reaction has a different rate at a different section of the reaction. Students presented an understanding that if a reaction occurs quickly, it will happen and all the reactants will be converted into products. The probably origin of this misunderstanding is that all the reactions go to full completion. If a reaction is fast it ends with full completion. Perhaps students did not appreciate the fact that every reaction reaches an equilibrium point where the forward and reverse rates of reaction are equal. That means that some of the products turn to reactants again. Alternatively, students may not understand the meaning of full completion of a reaction.

7.2.5 Discussion

Two Spontaneous Reactions revealed important misunderstandings about the use of Gibbs energy data where students mostly confused the kinetic and thermodynamic data. As it was stated at the beginning of section 7.2, thermodynamic data provides no information about the kinetics of a reaction. Students seemed to be unable to make this distinction between chemical kinetics and thermodynamics. Responses showed two different approaches. In the pre-test, the misunderstanding that *the bigger* $\Delta_r G^\theta$, *the faster the reaction occurs* changed to the misunderstanding that *the smaller* $\Delta_r G^\theta$, *the faster the reaction occurs* in the post-test. This significant shift can be explained by examining the students' reasoning. Students tended to use their everyday experiences to explain the phenomena in the pre-test, such as the rusting of iron, whereas they mostly tended to explain the phenomena in the post-test by the phase changes occurring in the reaction and energy exchange accompanying the reaction. It is apparent that teaching contributed some understanding as well as the formation of new misunderstandings. Hence, teachers and lecturers should be aware of this reality. Students developed a new way of approaching the problem as well as new misunderstandings.

7.3 Gibbs Energy

The idea being tested in *Gibbs Energy* is that the Gibbs energy change tends to become zero when the system goes to equilibrium and it becomes zero at equilibrium (see Appendix 8). The answer should include the fact that chemical reactions spontaneously approach the equilibrium state from both directions A → B or B → A. The equilibrium state has always a lower Gibbs energy than that of either the reactants or the products. As the reaction approaches the equilibrium the Gibbs energy change decreases and at the equilibrium state the change in Gibbs energy becomes zero. At the equilibrium state, the entropy of the universe attains a maximum level compared to the minimum Gibbs energy.

Table 7.3 Analysis of the students' responses to *Gibbs Energy*

Code	Description	Pre-test (n=45)		Post-test (n=44)	
		f	%	*f*	%
00	**Blank**	36	80	21	48
10	**Uncodeable**	-	-	-	-
20	**No understanding of the specific chemical idea tested in the question**	-	-	-	-
30	**Understanding of only some aspect/s of the specific chemical idea tested in the question**	2	-	5	11
31	As reaction proceeds Gibbs energy decreases	1	-	3	6
32	Correct drawing with no explanation or incorrect explanation	1	-	2	-
40	**Evidence for misunderstandings relating to the specific chemical idea tested in the question**	7	16	10	23
41	Incorrect drawings	7	16	10	23
50	**Evidence for misunderstandings relating to general chemical / scientific knowledge**	-	-	-	-
60	**Sound understanding of the specific chemical idea tested in the question**	-	-	12	27

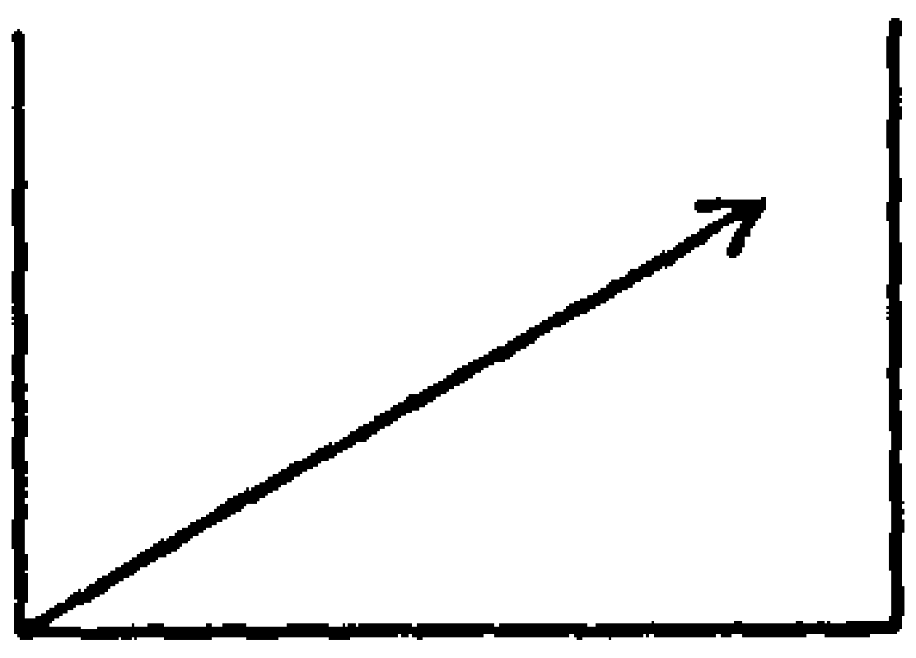
As can be seen from Table 7.3, four out of five of the responses were blank in the pre-test. Almost all the responses showed incorrect drawings and only a few of them included some partial understandings such as *correct drawing with no explanation* (coded as 32) or stating that *Gibbs energy decreases as reaction proceeds* (coded as 31). The post-test responses demonstrated significant improvements compared to the pre-test. The number of blank responses decreased to 48% and the total percentage of partial understandings increased to 11%. Also, in the post-test 23% of responses demonstrated *incorrect drawings* (coded as 41). No significant number of misunderstandings were identified. However, some misunderstandings were identified in less than 5% of the responses. These are:

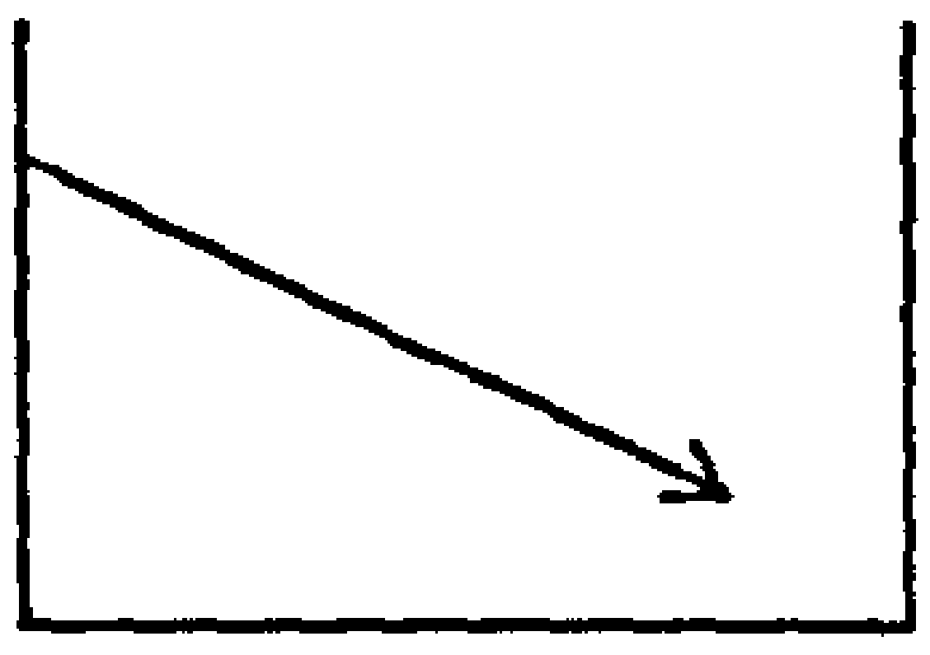
- *Gibbs energy is zero at equilibrium*
- *Gibbs energy is the energy that is required to start a reaction*
- $\Delta G = - T \Delta H$
- *Entropy only changes with temperature*

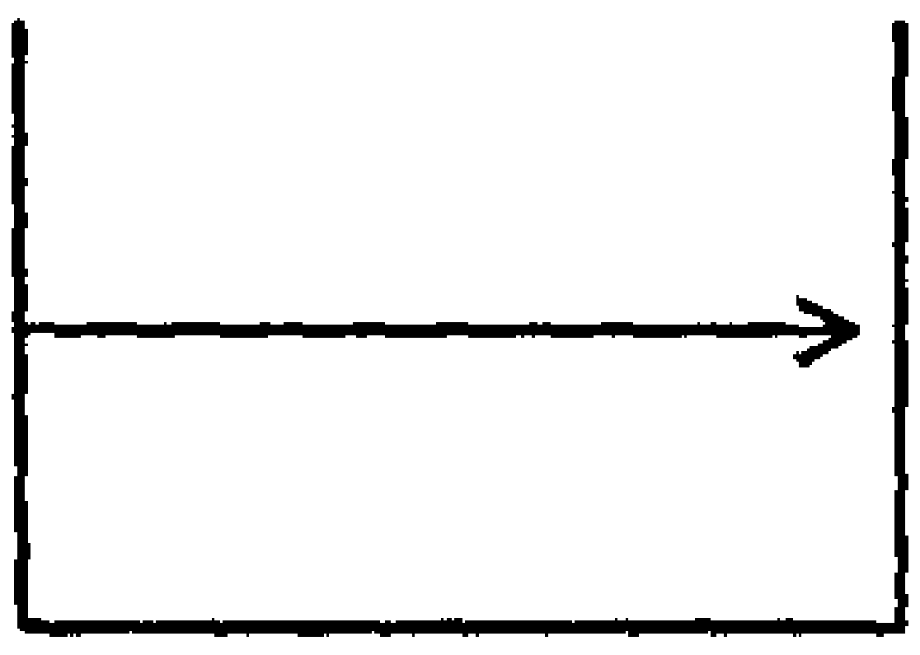
None of the pre-test responses showed sound understanding, while 27% of the post-test responses displayed sound understanding of the specific chemical idea tested in the question. This increase was expected because students had been taught Gibbs energy at this level in the physical chemistry course. Despite the teaching, the students' responses demonstrated significant misunderstandings in drawing the graph of Gibbs energy change versus extent of reaction. The students' drawings are shown and discussed in the next section.

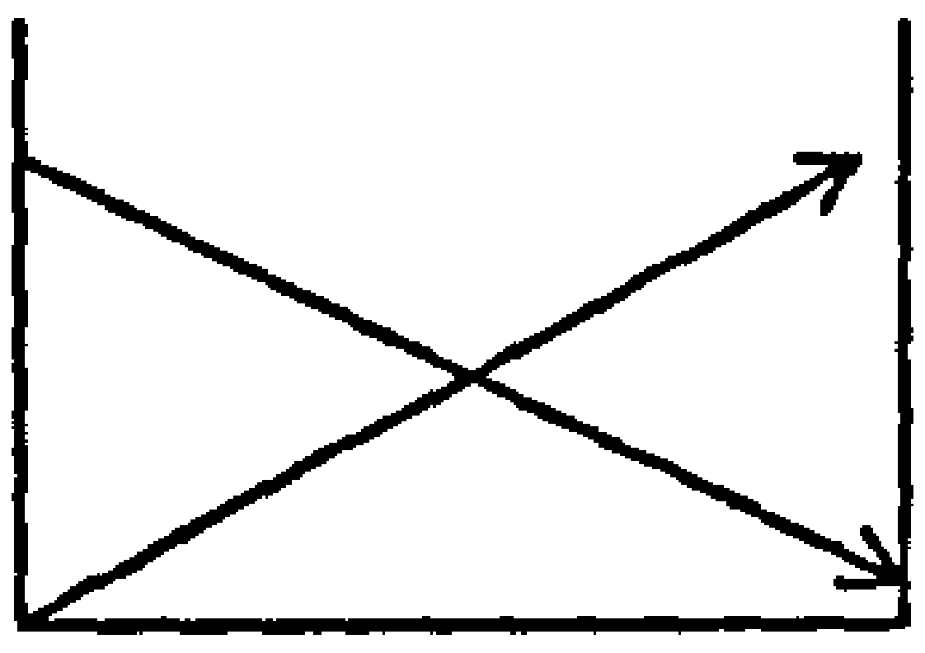
7.3.1 Incorrect drawings (41)

The students' responses to this question included some incorrect drawings. 16% of respondents in the pre-test and 23% of them in the post test drew the following incorrect representations to reflect Gibbs energy change versus extent of reaction for a hypothetical A - B reaction.


a

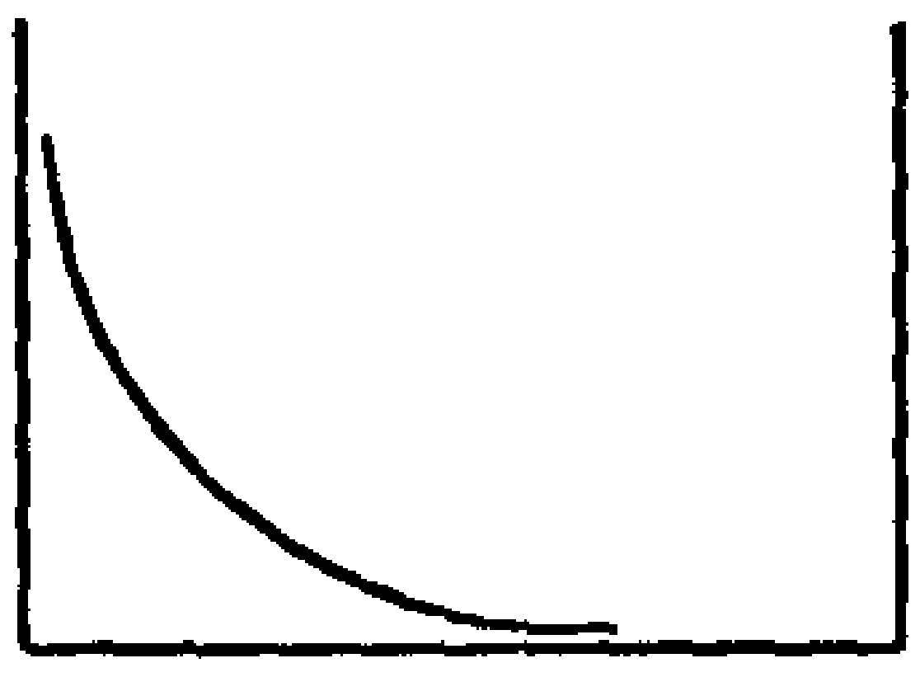

b

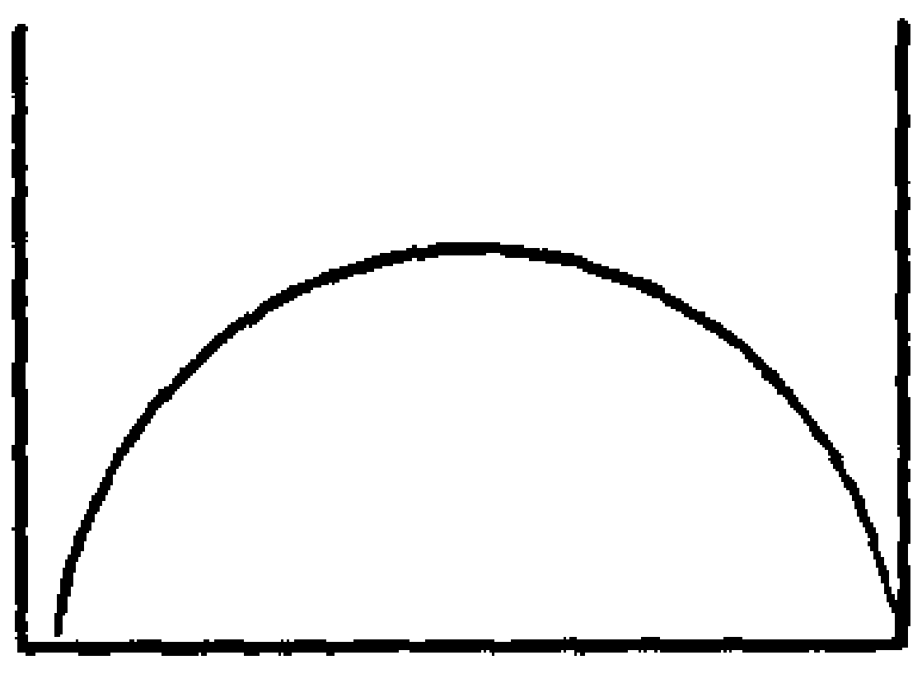

c


d


e


f


g


h

Two respondents drew (a) and none of them drew (h) in the pre-test. In the post-test the representation (h) was more common. Three out of ten respondents drew the representation (h). This was followed by representation (g). Diagrams d, e and f did not appeared in the post-test results.

7.3.2 Discussion

Gibbs Energy reflected the students' understanding of the Gibbs energy change accompanying a reaction, as well as the students' ability to present their conceptual understandings by drawing diagrams. The findings showed that only a few of the drawings were correct in the pre-test, but no explanation was provided, therefore the drawings may have been just a lucky guess. In the post-test, one in four students drew the correct graph and provided a correct explanation. However there were some incorrect drawings as shown above. In a study conducted by Banerjee (1985), in response to a similar question undergraduates mostly drew the graph (d). It was argued that Gibbs energy increases or decreases linearly to make the reaction spontaneous in either direction A → B or B→ A, depending on whether A (reactant) or B (product) had more Gibbs energy to start with (p.881). These incorrect ideas may originate from the fact that equilibrium is reached at the lowest Gibbs energy position as Banerjee argued. The fact that Gibbs energy change tends to become zero when the system approaches equilibrium and becomes zero at equilibrium had not registered in the undergraduates' mind. A few respondents stated that Gibbs energy becomes zero at equilibrium indicating that students' confused Gibbs energy change and Gibbs energy itself because Gibbs energy change becomes zero at the equilibrium state.

7.4 Conclusions

This chapter provides evidence of poor or no understanding of Gibbs energy amongst undergraduates. The key findings can be summarised as follows.

The questions testing the ideas related to Gibbs energy were not popular ones as the blank response rate ranged between 30% and 80%. It was also apparent that a large number of students who responded to the questions demonstrated no understanding. The significant misunderstandings were related to using thermodynamic data to estimate the changes in the kinetics of a reaction. Undergraduates failed to differentiate between the kinetics and thermodynamics of a chemical reaction perhaps due to an incorrect application of a physical sense into chemical thermodynamics as discussed in section 7.1. Some undergraduates' misunderstandings seemed to originate from the incorrect application of everyday experiences the chemical events. Some misunderstandings were also connected with the related concepts. As can be seen from the discussion in section 7.2, misunderstandings about Gibbs energy seemed to originate from no understanding of, or perhaps not knowing, related ideas such as equilibrium and reaction dynamic. Some also seemed to have originated from the students' lack of mathematical knowledge since physical chemistry lessons often involve a lot of complicated mathematical problems. A solution to this problem would be to teach the concept using less mathematics and to put more effort into teaching for conceptual understandings.

With respect to solving problems by using drawing skills and presenting the results as diagrams, undergraduates demonstrated a poor understanding and lack of capability. A high number of respondents (80%) left the question called *Gibbs Energy* blank in the pre-test. The students' drawings demonstrated a limited understanding of the idea and also displayed misunderstandings and confusions. Moreover, the results suggested that students were quite likely to develop new misunderstandings after teaching, indicating that Gibbs energy was a difficult idea to grasp.

The pre and post-interviews revealed some new misunderstandings about Gibbs energy which were not identified through the questionnaire. In the pre-interviews, students were only asked what they knew about Gibbs energy and why it is known as free energy. Students' responses showed either very little or no understanding of Gibbs energy. The only fact many students remembered was that Gibbs energy helps to estimate whether a chemical reaction occurs or not as illustrated below:

> *R: Could you tell me what do you know about Gibbs energy?*
>
> *I: ...emm... it helps us to estimate whether a reaction happens or not. Enthalpy and entropy are used in calculation of Gibbs energy. There is an equation.*
> $\Delta G = \Delta H - T\,\Delta S$ *. In this equation if* $\Delta G < 0$*, I think the reaction happens, if* $\Delta G > 0$ *it does not happen. If* $\Delta G = 0$ *it is in equilibrium (OI/E/*S_1*)*

A few of the interviewees demonstrated an understanding of what free energy means. However in general, they were not able to explain why Gibbs energy is known as free energy. The responses were mainly composed of guesses and showed little scientific explanation as shown below:

> *R: Gibbs energy is called as free energy as you know. Could you tell me why it was called as free energy? Where may it come from?*
>
> *I: It is a kind of energy when molecules are stable, they don't move, or it has in it when it is free... (OI/B/S_5).*

In another interview, one of the interviewees responded to the same question as follows:

> *I: free [long silence]* it may be energy of substances when they are free *(OI/E/S_5).*

The interviewees' responses reflect the everyday meaning of word 'free' unlike what meant by free energy in chemistry.

The post-interviews demonstrated some previously unidentified misunderstandings about Gibbs energy. Misunderstandings centred around the spontaneity and Gibbs energy, and reaction rate and the magnitude of Gibbs energy change. Students' understandings of spontaneity of a reaction were limited as they argued that if there is no external interference in the reaction it is spontaneous. Scientifically a spontaneous process is one which has a tendency to occur as determined by a negative Gibbs energy change (Selepe and Bradley 1997). Students' understanding of spontaneous shows parallels with meanings used in everyday language as Ochs (1996) argues. This can be seen from the following dialogue:

> *R: What do you mean by spontaneous?*

> *I: Without an external influence, if the conditions are available a reaction can happen without an external help, it happens spontaneously*
>
> *R: Can you give me an example?*
>
> *I: Yes, rusting, rusting of iron...*
>
> *R: Could you tell me how can you understand whether a chemical reaction occurs spontaneously or not? Is there a criterion? If yes, what is the criterion?*
>
> *I: Of course there is, reaction heat reaction enthalpy. At constant temperature, I mean in a spontaneous reaction, reaction enthalpy should be smaller than zero.*
>
> *R: Do you mean the reaction should be exothermic?*
>
> *I: ... emm... exothermic, endothermic in fact it is not conditional at the end. Enthalpy should be considered but we know like this (SI/B/S_{10}).*

The interviewee's understanding of spontaneity is not consistent with the scientific one. In many similar responses students repeated the everyday meaning of spontaneous. It is also clear from the dialogue that the interviewee did not understand the criterion for a spontaneous reaction which is a widespread misunderstanding amongst the undergraduates. They perceive enthalpy as a criterion for spontaneity of a reaction instead of Gibbs energy. Similar findings were also revealed by Selepe and Bradley (1997). Ochs (1996) argues that the word spontaneous, as used in the context of chemical thermodynamics, is inconsistent, and often misleading. It is commonly used without definition and its meaning varies amongst authors using it. The dictionary definitions do not fit the strict chemical definition of a negative change in Gibbs energy (p.954). As discussed in section 7.1.3, undergraduates did not understand the difference between thermodynamic data and kinetic data and often used thermodynamic data to estimate kinetics changes in a chemical reaction. Teachers and lectures need to be careful in distinguishing between kinetics and thermodynamics.

Chapter 8

Chapter 8

Student and Lecturer Perceptions of Learning Difficulties and Solutions

This chapter explores both the students' and lecturers' views of the learning difficulties which students experience in the physical chemistry course and possible solutions proposed by them to these difficulties. Student and staff views are important for two reasons. Students' views about a course influence their learning. The context of a course may be perceived differently by students and lecturers because of their knowledge, experiences, goals and needs. Staff perceptions influence the choice of curriculum and its implementation, and the nature of evaluation.

It is possible to understand student difficulties in chemistry if it is understood how their perceptions of the chemistry courses differ from lecturers' perceptions (Carter and Brickhouse, 1989). Much of the work in chemical education has been focussed on students' understandings of specific concepts or areas of the curriculum. Less attention has been paid to students' perceptions of chemistry programs in relation to matters such as course organisation, staff/student relationships and more general student characteristics (Kirkwood and Symington, 1996; p.339). In order to explore student perceptions of learning difficulties in respect of physical chemistry, students who completed the post-test were asked to discuss in groups of 2 or 3 students the difficulties they had faced and possible solutions there might be to these difficulties. The two questions were:

> *What do you think makes it hard for you to understand chemical ideas in physical chemistry? Please discuss with your friends in group and write them down.*
>
> *What do you think could be done to help you understand these ideas better? Please*

> *discuss with your friends in a group and write them down.*

Students were given one hour to discuss and write down their perception of the difficulties they faced. The sheet provided for their notes can be seen in Appendix 9.

In addition, two lecturers who had taught the physical chemistry course in the participating universities were interviewed following the student discussions. The interviews were unstructured and they were started with an introductory question:

> *'What do you think makes hard for the students to understand chemical ideas in physical chemistry?'*

Later on this was followed up with issues raised by the interviewees. The interviews were carried out in lecturers' offices and lasted about an hour. One of the lecturers agreed to be tape recorded and the other one did not and notes were taken during the interviews.

An analysis of the interview results was translated into two diagrammatic representations, one covering the perceived student learning difficulties and the other covering the ideas proposed to overcome these difficulties. Percentages were not calculated because only two lecturers were interviewed, however the views shared by both of the lecturers were indicated with an asterisk (*). Analysis of the results came from students' writings and was done in a qualitative way. Initially, all the responses were read, any patterns were identified and the first categorisation was done. Responses were tallied and finally similar categories were combined and the final categorisation was made and the percentages were calculated. The student perceptions were then translated into diagrammatic representations including the percentages which can be seen in the following pages. The student and lecturer perceptions of learning difficulties and proposed solutions were grouped under three headings:

- *course related,*
- *student related*
- *staff related*

Figure 8.1 Students' perceptions of learning difficulties in physical chemistry

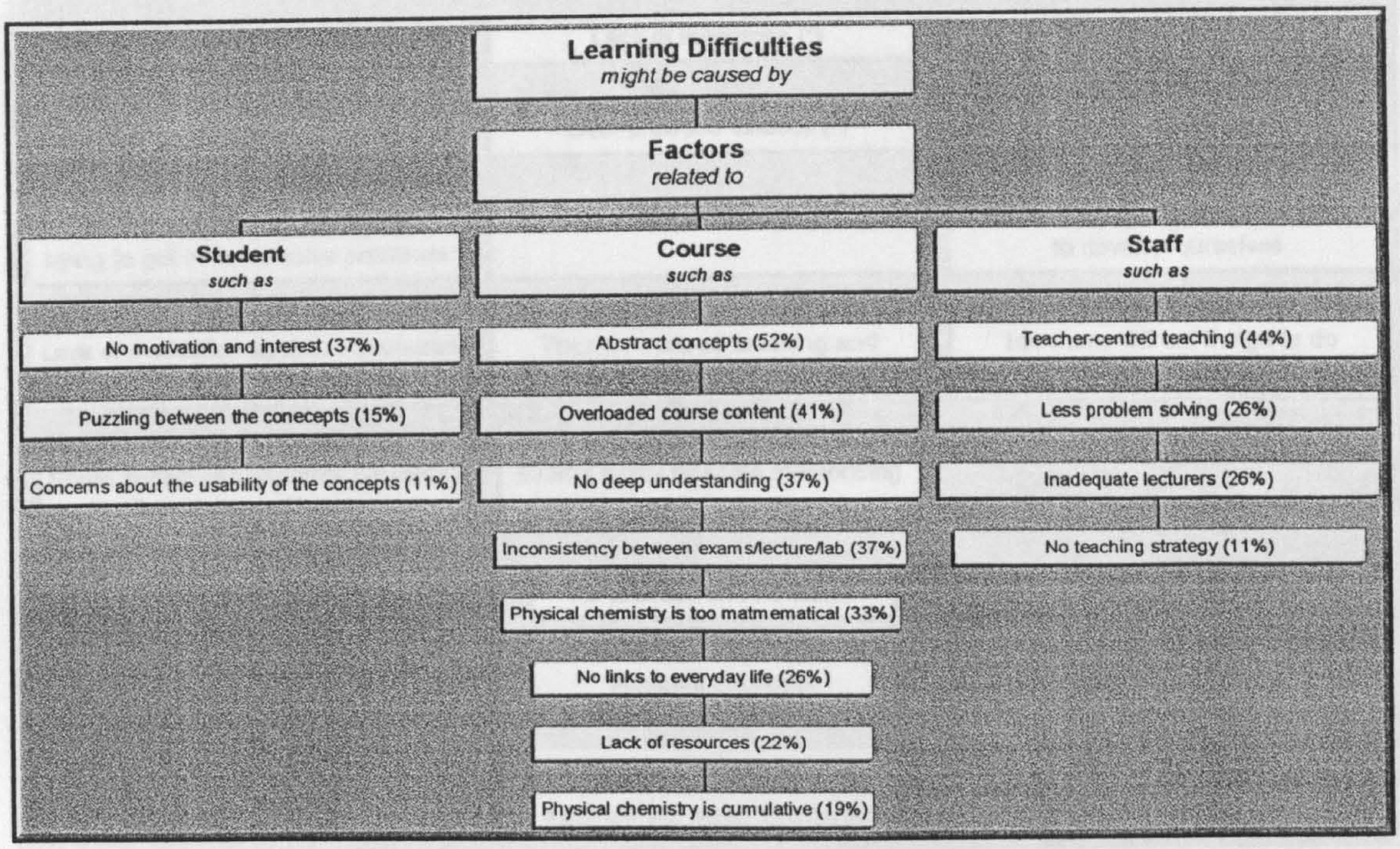


Figure 8.2 Lecturers' perceptions of students' learning difficulties in physical chemistry

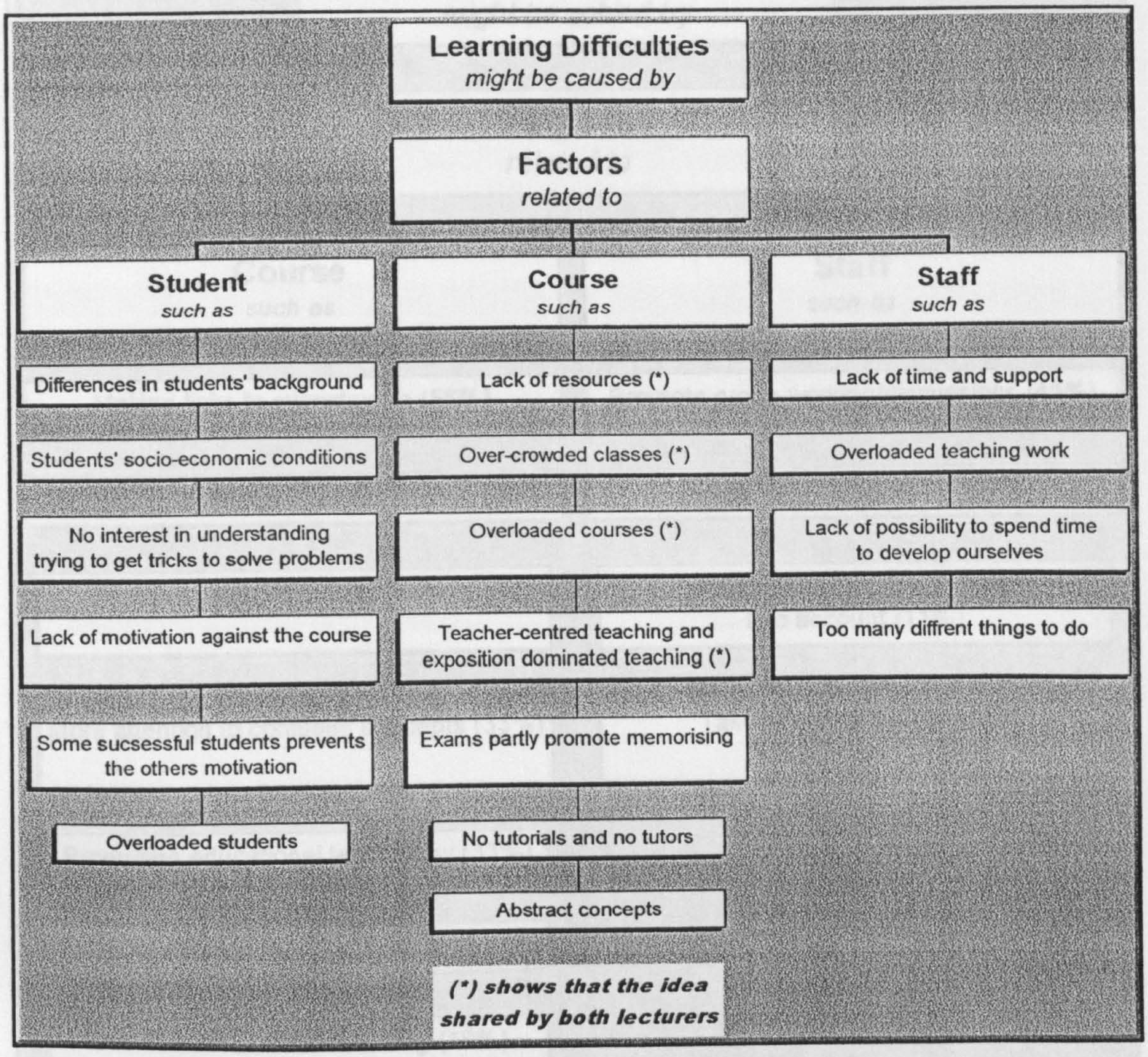


Figure 8.3 Students' perceptions of solution to learning difficulties in physical chemistry

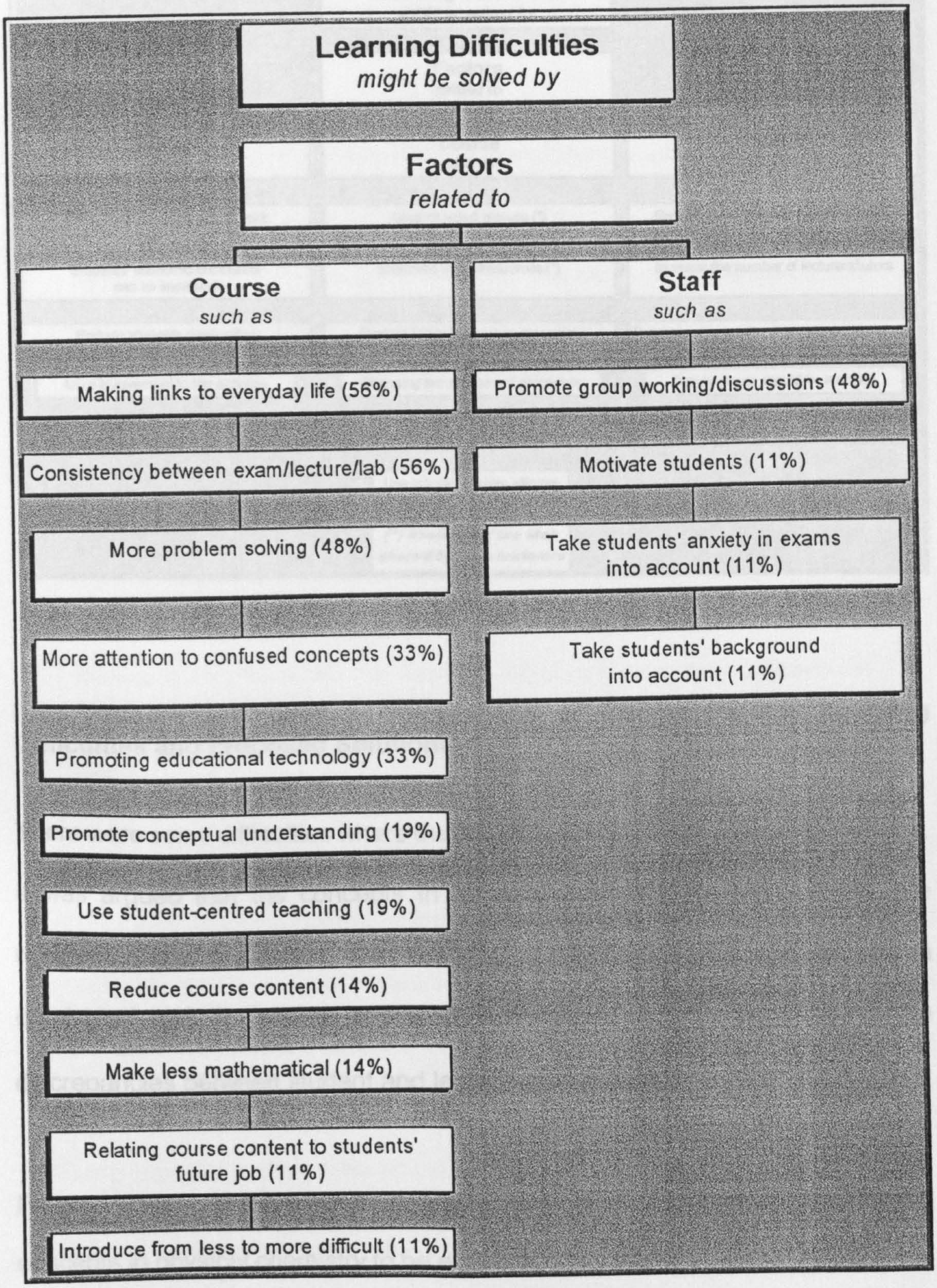
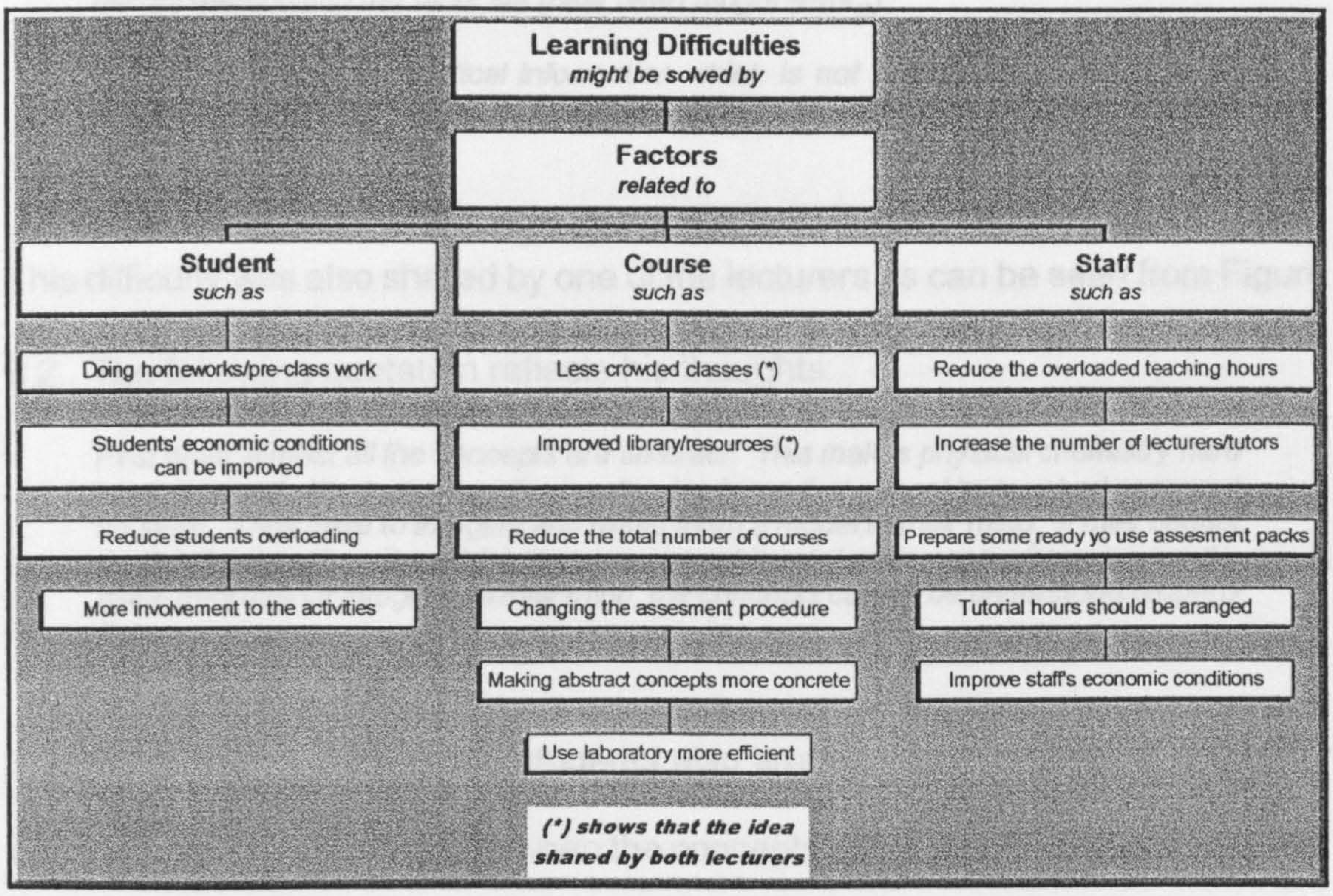


Figure 8.4 Lecturers' perceptions of solutions to students' learning difficulties in physical chemistry



8.1 Student and Lecturer Perceptions of Course Related Learning Difficulties and Proposed Solutions

There were some difficulties where the lecturers and students were in agreement. It was argued that the concepts in physical chemistry are too abstract, the resources are insufficient, the teaching is teacher-centred and exposition dominated and the course content is overloaded. There were also some discrepancies between student and lecturer perceptions.

Figure 8.1 shows that more than half of the students (52%) perceived the chemical concepts in physical chemistry to be abstract. They found it hard to visualise the abstract concepts, make them understandable and applicable to the macrophysical world.

> *Physical chemistry, as far as we see, is too abstract. We cannot see its link with everyday life. There are no concrete examples. Therefore our learning is based on mostly memorising the facts we have been taught (E/G_{15})*

> *There is too much theoretical information which is not properly exemplified to be understandable. The high amount of abstract information prevents thinking concretely (B/G_3).*

This difficulty was also shared by one of the lecturers as can be seen from Figure 8.2. The following quotation reflects his thoughts:

> *First of all, almost all the concepts are abstract. This makes physical chemistry hard to understand. Students have to visualise the ideas that cannot be touched or cannot be seen. They have to imagine and make them a model in their mind. If they cannot do this imagination, they think they cannot achieve. In this case whatever you do, since they cannot integrate in their mind, the concepts cannot be understood properly (L_2).*

In addition to this, 26% of the students also argued that the physical chemistry course does not make links between the concepts being taught and everyday life. as illustrated in the quotations below.

> *Making no link between the concepts and everyday life during teaching makes the concepts hard to imagine in our mind (E/G_{10}).*

> *We couldn't link some concepts to everyday life especially thermodynamic concepts (B/G_6).*

A significant number of students (56%) wish to see links between the concepts being taught in physical chemistry and everyday life as they believe that physical chemistry might be much more understandable if this could be achieved. They felt that if the connection between the concepts and their application to industry or everyday life was established they would be able to understand better. The following quotation reflects the students' thoughts:

> *During teaching, the abstract concepts might be related to the things that we can see. For example, during teaching entropy, more concrete examples can be given from the universe (E/G_2).*

Although the students generally did not provide any specific examples of how an abstract concept can be made more concrete, it is apparent that there is an overwhelming demand for relating the concepts to everyday life. This was also proposed by one of the lecturers and provides further evidence that lecturers are aware of the student difficulties. However, when it comes to practice, they also find it hard to make the concepts concrete enough, hence one lecturer admits:

> *We have an overloaded teaching duty. We don't have enough time to have a look back and evaluate our teaching. If we had less teaching duty and had a chance to do more preparation for the course, I am sure it would make a difference (L1).*

The second issue that both students and lecturers were agreed on was the overloaded courses and course contents. 41% of the student responses stated that the course content was overloaded. It was also recognised by both lecturers that the course content is overloaded and there are too many courses. Both anecdotal experiences and research, such as Carter and Brickhouse (1989) and Kirkwood and Symington (1996), provide evidence that students are dissatisfied by overloaded course content. Students complain that there are too many new concepts to be learned in a short period of time. They also stated that lecturers decided to come to a certain point and tried to reach the line even if students did not understand.

Although a highly significant number of students (41%) complained about the overloaded course content, only 14% of them proposed that reducing the course content might promote better understanding. Though the lecturers agreed with the students, they stated it in a slightly different way by agreeing that there are too many courses which students have to complete. The lecturers proposed that reducing the overall number of courses would help students. It appears that there is a need for a careful examination of undergraduate curricula and their implementation and also the lecturers' teaching responsibilities.

Almost one in five (22%) of the students complained about the lack of resources and quality textbooks. They stated that the facilities, such as library, study rooms in the department, handouts or written documents which can be used for self-study, are either not available or not adequate. In this category, the biggest complaint was about the shortage of quality textbooks written in Turkish. The quotation below reflects the students' views.

> *There is no certain textbook [in Turkish] that the lecturer follows. There must be a proper textbook written in Turkish which we can follow. The books in the library are either too old or written in English. The lecturer cannot be as much help as a quality textbook (we don't blame the lecturer). According to us, book plus lecturer would be better (E/G_1).*

The students' views were also shared by the lecturers, who also argued that resources were insufficient stating that it is not fair to blame students for not doing library searches or study.

> *We are having difficulties in asking students to go to the library and make searches, in many cases the library is not good enough, either the books are too old or they are in English, therefore students cannot understand (L_2).*

As seen from the quotation, students' and lecturers' views overlap. It was proposed by both lecturers that the library facilities and resources should be improved as they are important for the students, but there is an issue about how to use available resources effectively. Experiences also shows that many first year students do not know how to use the library because they are not formally introduced to it. Evidence suggests that this may discourage students from using the library.

The last point that both students and lecturers seemed to be agreed on was the fact that teaching was mostly dominated by the lecturer, and exposition-dominated methods were used. 44% of the students showed dissatisfaction about the teacher-centred teaching by stating that:

> *As is the case in the other courses, physical chemistry is also dominated by the instructor. The student is always passive (E/G$_{12}$).*

Both of the lecturers admitted that teaching is mostly dominated by the lecturer and that this is unlikely to change. Due to the lack of resources as regards educational technologies exposition-dominated teaching is preferred. One of the lecturers gave an interesting example of using a video in teaching where he argued that using a video made the students very passive.

> *Last year I used video a couple of times. I had difficulties at the beginning. Students' learning was less than I expected. Also, students got bored. They started to ask when it will finish? When will we go out? I think it was partly because of the content and quality of the videos (L2).*

It appears from the quotation that the lecturers clearly expected improvement in students' learning by using a video and therefore the result was a disappointment. It is also important to recognise that the content of the videos is important as well as the knowledge how, where and when to use them. Since mis-use of educational technology may discourage staff from using it, they may prefer exposition-dominated teaching methods, as these represent one of the best teaching methods in the circumstances. Despite the lecturers' views, one in five of the students felt that student-centred teaching and using educational technology might promote better understanding.

Although there was a great deal of agreement on the learning difficulties between students and lecturers, there were some important disagreements as well. In this sense, 37% of the students argued that there is no promotion of deep understanding, and that they learn to pass the exams, not to understand because of exam procedures.

Evaluation procedures are generally more criticised. The accuracy, consistency and the validity of the assessment procedures have been found to be problematic from the students' point of view by Carter and Brickhouse (1989). However, in this study, the biggest student dissatisfaction was about the written exams which force the students more to memorise instead of understand. Students simply argued that they have to memorise the concepts or equations in order to be able to write something in the exams. Since the facts are memorised, they easily forget them after the exams. In addition, some of the students also argued that there is no need to understand the idea behind the concepts, because they will be tested by the exams in which they have to know how to manipulate the data to solve the problems. Therefore among the proposed solutions the idea that more problem solving might help to improve understanding was shared by 48% of the students. The following quotation reflects the student perspectives.

> *There is not enough problem solution in the class but in the exams we are asked to solve problems (E/G_{11}).*

The students' dissatisfaction with the exam procedure was partly recognised by one of the lecturers as shown below:

> *L: ... Students are not aware of the importance of conceptual learning as I said above. They want problem solving. I ask 'is there anything that you did not understand?' after teaching. They still ask me to solve problems. This shows that we are not in line with the students. I am trying to teach them the ideas behind the concepts but they still want to learn the tricks that help them in the exams to solve the problems. They don't seem to be willing to learn the concepts themselves...*

> *R: Is this something that exams promote?*
>
> *L: Of course exams play an important role but it cannot be totally attributed to the exams, because students have a habit of memorising to pass. It is difficult to change this habit, because it is easy... (L_2).*

Despite the lecturer's argument that students do not want conceptual understanding, 19% of the students stated that promoting conceptual understanding might improve their learning of physical chemistry. In relation to this issue, one third of the students proposed that if more attention was given to frequently confused concepts and if the concepts were introduced from easy to difficult the students' understanding of physical chemistry might improve.

The inconsistency between exams/lectures/lab was perceived as a problem by 37% of the students and one of the lecturers mentioned this issue. In one of the participating universities, the laboratory and the theoretical course were in the same semesters, but the laboratory course was in the year after the theoretical course had been given in the other participant university. Many of the complaints were focussed on the theoretical course content and the laboratory course content. Students appeared to want to do experiments in the laboratory course that related directly to the information taught in class.

> *The theoretical course and laboratory course are not parallel to each other. We have to do experiments about subjects that we don't know. Therefore we can't make links between them (B/G_2).*

There was an overwhelming demand by 56% of the students that consistency between exams/lecture/lab should be established. This was the second most refquently proposed idea by the students to improve learning. It seemed that this demand is either missed or not perceived as an important factor by the lecturers.

Carter and Brickhouse (1989) also found that 63% of the students and 55% of the lecturers are not satisfied with the consistency between exams, lecture and laboratory. There was anecdotal evidence to support the students' view and also partly explain the lecturers' view as to why different topics are covered in laboratory courses. It was argued that the wide content of physical chemistry was spread out between the theoretical course and laboratory course. For example, in one of the participating departments the phase diagrams are not taught in the theoretical course but covered in the laboratory. This has been perceived by the students as problematic because they argue that doing experiments in a topic that they have not been taught makes it hard to understand.

It has been always a subject of discussion among students that the course is dominated by mathematics with one in three arguing that physical chemistry is too mathematical. The same also applies to chemistry in general. Carter and Brickhouse (1989) found that 16% of the students and 36% of the lecturers perceived chemistry as too mathematical. The Kirkwood and Symington (1996) study also contains similar evidence. The results of this study show that one of the most common complaints about the lecturers was the use of a high level of mathematics whilst giving less priority to the conceptual aspects of the chemical concepts as illustrated in the quotations below.

> *Physical chemistry should escape from the derivations and integrals. It should be based on experiment not on theory. If possible every piece of information given should be supported by experiments. Instead of forcing us to memorise, the conceptual learning should be promoted* (E/G_1).

> *The mathematics dominant course makes it hard to understand* (E/G_7).

Despite the fact that 33% of the students complained about the mathematical content of the course, only 14% of them proposed that making the course less mathematical would help improve understanding.

Almost one in five of the students (19%) perceived physical chemistry as cumulative. It was argued that if a student missed a lecture it was very difficult to catch up as subsequent lectures rely heavily on previous ones. Some of the students' responses are quoted below to show the arguments.

> *If you don't attend one or two lectures, you cannot understand the following lectures (E/G_8).*
>
> *The concepts are connected with each other. If you don't understand one, it is impossible to understand the following one. In addition, every concept has some equations and these equations cannot be used for the following concepts. Therefore we cannot make a link between the concepts (E/G_{13}).*

These quotations indicate that students cannot see the subjects as a whole and their knowledge stays incomplete and fragmentary. These results correspond with Carter and Brickhouse's (1989) study who found that 67% of the students argued that chemistry was cumulative.

On the other hand, there were some issues that lecturers perceived as preventing better learning which were not recognised by the students. The first one that both lecturers agreed on were the over-crowded classes. They proposed that reducing the size of the classes might enhance teaching and learning, since different teaching methods could be applied, for example group working and group discussions and also small class sizes help to offer better facilities in the laboratory for the students. One of the lecturers stated that the lack of tutors and tutorial hours was also discouraging better teaching. He proposed that more tutorial hours should be arranged, but to do this there must be adequate staff.

Finally, there were a couple of issues that were raised by the students to promote better understanding. The use of educational technology such as videos, slides, demonstration kits, computer programs etc. was advocated by 33% of the students. There were some concerns about the relationship between the course content and students' future jobs. Students seemed not to be happy with the high level of thermodynamic content of the course and 11% of them proposed that the course content should be related to students' future jobs. Both the research and anecdotal evidences suggest that students have concerns about how they will benefit from such a high level of knowledge of physical chemistry in the future. Most of the graduates are likely to become primary school teachers because there is a surplus of chemistry teachers in secondary schools. Because of this, they do not see any need to advance their level of physical chemistry knowledge.

8.2 Student and Lecturer Perceptions of Student Related Learning Difficulties and Proposed Solutions

It seemed that student and lecturer perceptions of students' learning difficulties were generally different. The most commonly shared idea was that students have no interest or motivation for the course because of their lack of understanding. This was shared by 37% of the students and by one of the lecturers as well. As seen in the following quotation, lack of understanding de-motivated the students.

> *When students did not understand, it has been labelled as 'difficult' and students lose his/her motivation. Therefore students must be more motivated (E/G_2).*

11% of the students thought that they should be motivated by the staff. Although the lecturers agreed that students' motivation needed to be improved, they did not clarify how this could be done.

Less than 10% of the students perceived their background as the main source of their difficulties. In addition 15% of the students argued that they were confused about the concepts. Their argument was based on the fact that there were too many related concepts which could not be easily differentiated from each other such as heat and temperature, internal energy, enthalpy, entropy, Gibbs energy and Helmholtz energy.

Lecturers perceived the difficulties in a slightly different way. They considered that students' socio-economic conditions were important such as students background, economic conditions and the relationship with their family and friends. One of the lecturers stated that it was difficult to advise the students to buy books or educational aids because of their limited budget. Therefore improving students' socio-economic conditions might promote the students' understanding.

It was also recognised by the lecturers that students have a heavy work load.

> *... physical chemistry is not the only course that students take. There are too many courses at the same time. Students are also responsible for those courses and they have to spend time on them as well. If you look at to the number of courses that students have to get, you will see that it isn't right to blame the students. Even if some of the courses are not tough, still they have to do required tasks for those courses. In this case, students are tempted to do surface learning. They don't want to focus on the conceptual aspects. On top of that, the lack of resources is an important issue (L_2).*

Staff perception was that by reducing the students' work load better understanding would be promoted. They also proposed that more involvement in class activities, homework and pre-class work might improve the students' understanding of physical chemistry.

Finally, one of the lecturers considered that some successful students affect the motivation of others. This was also raised by a small number of students (less than 10%) who argued that:

> *The lecturer teaches the course to some individuals and forgets the rest. This affects our concentration on the lesson (E/G_7).*

The lecturer stated that:

> *... in a class, if one individual, out of fifty students, seems active it sometimes discourages the others. The rest think that he/she has already got the lecturer's attention so we don't need to do anything... therefore to avoid this, we need to develop different perspectives (L_2).*

Here the lecturer is clearly aware of the problem and attempts to find a solution to it.

8.3 Student and Lecturer Perceptions of Staff Related Learning Difficulties and Proposed Solutions

Many of the student perceptions of learning difficulties relating to staff were about the teaching methods. It seemed that students were not happy with the way they had been taught. The most common complaint (44%) was that more teacher-centred and exposition-dominated teaching strategies were used as illustrated below:

> *As in the other courses, physical chemistry is also dominated by the instructor. The student is always passive (E/G_{12}).*

Another dissatisfaction raised by 26% of the students that there was not enough problem solving in the class.

> *There is not enough problem solutions in the class (B/G_7).*

As discussed in section 8.1, the students generally tend to want to improve their problem solving skills because success in the exams mostly depends on their problem solving abilities. This dissatisfaction was also found by Carter and Brickhouse (1989) who reported that 68% of the students and 64% of the lecturers were aware of the problem. During the interviews the lecturers also recognised the students' point of view. However their answer was the shortage of time and supporting staff.

Some 26% of the students argued that lecturers do not come to class adequately prepared and do not clearly distinguish between different concepts as illustrated below:

> *The lack of subject knowledge of the lecturer or no preparation for the lecture makes it hard to understand physical chemistry (B/G11).*

This was perceived by 64% of the lecturers and 26% of the students in the Carter and Brickhouse (1989) study. One quarter of the students in this study were unsure about the subject knowledge of the lecturers.

Around one in ten students complained that the lecturer did not follow a defined teaching strategy.

> *We haven't understood which teaching methods the lecturer has been using (E/G_6).*

There were also some other complaints related to the staff, which occurred infrequently and therefore were not shown in the diagram. They were:

- *Lecturer uses a high level of scientific language*
- *Lecturer focusses on certain students in the class*
- *Lecturer's voice cannot be heard from every part of the classroom*

- *We get less support from the teaching assistants in laboratory*

From the staff point of view, the majority of the difficulties were centred around the lack of time and support given to the staff, overloaded teaching schedules and management related duties. It was proposed that lecturers' teaching hours should be reduced, tutorial hours and tutorials should be arranged, and also that the staff's economic conditions should be improved. The preparation of ready to use assessment packs was also another alternative solution proposed by one of the lecturers.

8.4 Discussion

This chapter looked at the student and lecturer perceptions of students' learning difficulties in physical chemistry and their possible solutions.

Although it is not appropriate to generalise from a single study, the findings suggest that students and lecturers sometimes perceive the learning difficulties differently . The results showed that lecturers and students were partly in agreement on the students' learning difficulties which related to the course, and there were discrepancies about student and staff related difficulties as well as some course related difficulties. Students were critical of the course content, the resources available, the lecturers and their teaching methods. However, only a few students blamed themselves that they do not do the work on their side.

Lecturers generally focussed on the factors that related to the course, such as overcrowded classes, lack of resources and staff, and indirect factors, such as student background and socio-economic conditions. Lecturers partly blamed themselves as well. The findings suggest that there is a great deal of discrepancy between staff and student perceptions, although some points about the course related difficulties were shared by both sides. These common points and discrepancies may be used to improve the quality of teaching and learning.

Among the students' difficulties, the abstract nature of the thermodynamic concepts was a common theme. This is also recognised by the lecturers. The other difficulty which related to the nature of the thermodynamics, or general physical chemistry, was the mathematical content of the course. One in three students perceived physical chemistry as too mathematical.

The remainder of the difficulties relating to the course focussed either on teaching methods or the physical conditions of the teaching environment. The lecturers generally emphasised the difficulties relating to the poor teaching environment which prevents better teaching. However the interview data suggests that the lecturers have not given sufficient thought to how students learn, despite the large amount of literature on that issue, for example Ramsden (1992) and Kyriacou (1986). This might be due to staff's pedagogical content knowledge. It seems from the students' concerns and proposed solutions that there is a demand for the pedagogical aspects of teaching and learning to be considered. For example, propositions such as promoting group work and discussions, motivating students, using educational technology in teaching, focussing on conceptual understanding, establishing consistency between the exams, the lectures and the laboratory, as well as promoting student-centred teaching, may help to achieve better understanding.

Chapter 9

Chapter 9

Findings and Discussions

The purpose of this research is to identify and classify chemistry undergraduates' misunderstanding of thermodynamics ideas in physical chemistry such as internal energy, enthalpy, entropy and Gibbs energy, together with the sources of these misunderstandings. The main findings of this research study will be discussed in relation to the aim of the study and the research questions proposed. The first research question which was, *what are the third year Turkish chemistry undergraduates' misunderstandings about internal energy, enthalpy, entropy and Gibbs energy?,* will be answered and a concise summary of the misunderstandings which were identified will be given. Then the second research question, *where do these misunderstandings arise? What are their sources?,* will be answered and the possible sources of the students' difficulties in learning these ideas will be discussed. Finally, implications for teaching will be discussed in the light of the literature. The chapter ends with an evaluation of the study.

9.1 Undergraduates' Misunderstandings about Internal Energy, Enthalpy, Entropy, Gibbs Energy and Related Ideas.

In this section, the misunderstandings which were identified will be summarised. The misunderstandings given in the main data presenting chapters were, in general, question-specific. Sometimes the same misunderstanding appeared in a different question but in a slightly different wording and were also repeated in some cases. Therefore, these misunderstandings will be revisited and if necessary the wording will be reconsidered and summarised in this section.

9.1.1 Misunderstandings about internal energy and related ideas

Students were asked about internal energy and related ideas such as potential energy and kinetic energy. It appeared that the following misunderstandings related to potential energy were common among the undergraduates.

- *Potential energy of ideal gases is zero because ideas gases have no volume.*
- *Potential energy of ideal gases is zero because ideal gases have maximum/minimum velocity.*

The above misunderstandings and the others listed in Table 4.1 indicate that undergraduates still do not understand potential energy. It appears that the source of the difficulty may partly come from the students' lack of knowledge of the particulate nature of the matter and the kinetic molecular theory. The findings of studies about students' ideas regarding the particulate nature of matter (Novick and Nussbaum,1978,1981) and (Benson *et al* 1993) are consistent with the findings of this study. It also appears that undergraduates have difficulties in differentiating real gases and ideal gases (see section 4.1.1). In addition, as discussed in section 4.1.6, misunderstandings about potential energy may arise from inadequate differentiation of the definition of *gravitational potential energy* and *coulomb (electrostatic) potential energy.* Potential energy is mostly defined as gravitational potential energy in the textbooks (also by teachers), but coulomb (electrostatic) potential energy has a greater importance in chemistry (Atkins, 1997). This study shows that almost all the undergraduates when asked to define the potential energy gave the definition of gravitational potential energy. It seems that this is one of the main sources of the students' misunderstandings of potential energy. Therefore, it appears that students should be able to distinguish between two aspects of the potential energy and also realise that coulomb (electrostatic) potential energy has more use in chemistry.

The misunderstandings which related to kinetic energy are summarised as follows:

- *Kinetic energy is only related to the mass/weight of the particles.*
- *Kinetic energy is only related to the velocity of the particles.*
- *Kinetic energy is related to the number of collisions of the particles.*
- *Kinetic energy is related to the pressure/volume of the gases in a container.*

The above misunderstandings were widely identified amongst the undergraduates. As seen from the misunderstandings listed, kinetic energy of the gases (see *Helium and Carbon Dioxide* in Appendix 8) was attributed to the different variables. Some of the students believed that mass/weight is the only factor which alters the kinetic energy whilst some of them thought of velocity as the only factor. There were students who believed that pressure, volume or the number of the collisions of the gas particles are the factors which alter the kinetic energy. It emerged that students' difficulties with kinetic energy come from two sources. The first one is a misinterpretation of the conventional equation of kinetic energy, $E_k = \frac{1}{2} m V^2$. Students who chose this equation as a starting point ended up with the misunderstanding that *the more molecular mass the more kinetic energy* and *the faster movement the more kinetic energy*. These generalisations are not applicable to every case. As explained in section 4.2.8, neither molecular mass nor velocity determine the kinetic energy alone but both contribute together. The second source of misunderstandings appeared to be the students' fragmentary knowledge of kinetic molecular theory. It emerged from the students' responses that the same respondent attributed kinetic energy only to the molecular mass of the gases, but in another sub-section of the same question, he/she attributed kinetic energy only to the velocity of the gas particles. This kind of response indicates that the essence of the kinetic energy and the kinetic molecular theory has not been grasped. Students have a surface understanding of the idea and therefore failed to apply their knowledge to molecular level discussions. These findings support the argument by Benson *et al* (1993) that scientific laws and statements are easy to memorise but getting inside the phenomena is not so.

Misunderstandings related to internal energy are summarised as follows:

- *Internal energy of perfect gases decreases if the volume increases/pressure decreases in isothermal conditions.*
- *Internal energy of perfect gases increases/decreases by W (expansion work) in the case of isothermal expansion.*
- *Internal energy of perfect gases increases if the number of collision of the particles increases in isothermal conditions.*

These misunderstandings appear to be related to the students' lack of knowledge of potential energy and kinetic energy of perfect gases because they were identified in the responses given to the question *Perfect Gases* (see in Appendix 8) which examines the students' understanding of internal energy change of perfect gases under isothermal expansion. The idea that internal energy is the sum of the kinetic energy of all particles and potential energy arising from their interactions with one another was tested. Since the students did not understand potential and kinetic energy properly, as a result they developed the above misunderstandings relating to internal energy. It also appears that misunderstandings may have originated from the misinterpretation of the equation, $\Delta U = q + W$ as discussed in section 4.3.3. Students thought that at constant temperatures heat change is equal to zero, hence internal energy should only change as a result of work. Students also failed to differentiate the perfect gas and real gas cases.

Another misunderstanding which related to the internal energy was:

- *Internal energy of an isolated system increases if a chemical change occurs inside the system.*

This misunderstanding showed that students did not consider the whole system but only the changes which occur inside the system such as temperature or pressure increase as a result of a chemical change (see section 4.4.6). Rozier and Viennot (1991) pointed out that most thermodynamic problems are multi-variable and students consider them as a series of changes and therefore consider first one of the variables and then an other instead of dealing with them as a whole. This type of reasoning was described as *linear casual reasoning* by Rozier and Viennot (1991).

Another group of misunderstandings which related to the change of internal energy were:

- *Internal energy of a system does not change by doing work on the system.*
- *Internal energy only changes with q (heat) given to the system.*
- *Internal energy change is only equal to the work done on the system.*
- *Heating a system causes more change in internal energy than doing work on the system.*

These misunderstandings show the students' difficulties about essential elements of internal energy which are heat and work. Students confused between heat and work. The majority of the students argued that energy transfer as heat is the major source of the internal energy chance. This may be due to the fact that energy transfer as heat causes an apparent change in a system in many more cases than work does, as Erickson *et al* (1985) argue.

9.1.2 Misunderstandings about enthalpy and related ideas

This study revealed various misunderstandings about enthalpy and related ideas. The most common one was:

- *Misunderstanding lattice enthalpy and hydration enthalpy.*

A highly significant number of students (almost half of the respondents) confused the lattice enthalpy with sublimation and formation enthalpy and more than half of the respondents failed to identify the hydration enthalpy indicated on an energy level diagram. Amongst the responses given to define the hydration enthalpy, activation, liquidation, ionisation enthalpies were common. These responses support the argument that students are most likely to memorise the definition of the processes but they fail if they are asked to recognise the enthalpy changes which accompany the processes on an energy level diagram as discussed in sections 5.1.1 and 5.1.2.

Students were also unable to estimate enthalpy changes of a reaction. Misunderstandings revealed were:

- *Dissolution process is always exothermic/endothermic.*
- *The dissolution of NaCl is an exothermic process.*
- *During the dissolution of NaCl more heat absorbed from the surrounding water than that of KI.*

Almost 50% of the respondents in the pre-test failed to estimate whether a reaction exothermic or endothermic by looking at an energy level diagram, but this dropped to 10% in the post-test. This high percentage indicates that students are having problems with very basic ideas about enthalpy. The findings of this study does not support lecturers' assumptions that students already know these ideas. The other misunderstandings listed above suggest that students have no clear conception of energy changes involved in dissolution processes. Perhaps students thought that the dissolution process only consisted of breaking of the intra-molecular bonds in water, which requires energy, and this resulted in the misunderstanding that *dissolution is an endothermic process*, or if they thought that the second stage of the dissolution which is the hydration of the dissolved ions in the water is an exothermic process, this resulted in the misunderstanding that *dissolution is an exothermic process*. Students also had difficulty in differentiating the dissolving and dissociation processes. The results also suggest that students are likely to make over generalisations by using data representing only one or two cases.

There were also misunderstandings which related to the energy change and spontaneity of a reaction as summarised below:

- *Bond making requires energy / bond breaking releases energy.*
- *Endothermic reactions cannot be spontaneous.*

These are the most common misunderstandings reported in the literature. Cross age studies have reported these misunderstanding including Boo (1998), Thomas (1997), Barker (1995) and Johnstone *et al* (1977). It is important to note that undergraduates at advanced levels still had these incorrect ideas. For example, over 30% of the respondents have the second misunderstanding. This is a highly significant percentage for advanced level chemistry undergraduates and should be considered in detail. There were also some undergraduates who had the reverse of this misunderstanding as shown in section 5.4.7. The possible sources of these misunderstandings are discussed in sections 5.2.1, 5.2.1, 5.4.6 and 5.4.7 respectively.

In addition some of the respondents argued that:

- *Formation enthalpy is always exothermic.*
- *A spontaneous reaction is always exothermic.*

The first misunderstanding is more likely to originate from the fact that most formation reactions are exothermic. There is a relatively low number of endothermic formation reactions such as formation of $C_2H_{2(g)}$, $C_2H_{4(g)}$, $NO_{(g)}$, $N_2O_{(g)}$ and $NO_{2(g)}$ at 298K. Students appeared to understand that the source of the energy is different in exothermic reactions and endothermic reactions. Only a small number of respondents were aware of the fact that chemical bonds are the energy stores and therefore the energy change of a reaction is related to the strength of the bonds broken and made in a reaction. The second misunderstanding reported is most likely to have resulted from the misinterpretation of the fact that *exothermic reactions occur spontaneously.* Perhaps they thought the reverse was correct as explained in section 5.2.4.

Students also misunderstood the enthalpy change itself:

- *Enthalpy change is the energy transfer at constant volume.*

This misunderstanding was observed in almost half of the undergraduates' responses. The reasons behind the misunderstanding are discussed in detail in sections 5.3.3, 5.3.4 and 5.3.7. However, it appears that the confusion may originate from the lack of understanding of constant pressure and constant volume cases in chemical reactions, difficulty in differentiating heat and temperature and energy transfers involved in chemical reactions and also inaccurate knowledge of internal energy and enthalpy.

Misunderstandings which related to the kinetics of a reaction were:

- *Exothermic reactions occur fast.*
- *Endothermic reactions occur fast.*

These were identified in a quarter of the respondents. It indicates that students easily confuse the kinetics and thermodynamics of a chemical reaction as discussed in sections 5.4.1 and 5.4.2. The confusion of thermodynamic quantities and kinetic quantities was common throughout the responses given to the question called *Two Hypothetical Reactions* (see Appendix 8) and discussed in section 5.4.10.

9.1.3 Misunderstandings about entropy and related ideas

Students' responses about entropy and related ideas revealed a relatively low number of misunderstandings in comparison to the previous ideas such as internal energy and enthalpy. There was a high number of blank responses (one in three did not respond to the questions) partly contributing to the low number of misunderstandings. Students did not feel that they adequately understood the entropy changes accompanying to the system and the surroundings. It appears that most of the students have difficulty in understanding the terms '*disorder*' and '*spontaneity*'. It appeared that students' understood '*disorder*' as chaos, randomness or instability in some cases. Disorder and entropy were considered as synonymous in other cases. They also thought of '*spontaneity*' as a random rapid movement or as an undirected action. Students' habits of using mathematical equations to solve the problems associated with conceptual understandings seemed to cause misunderstandings. Among the misunderstandings identified the following ones were common:

- *Entropy is disorder.*
- *Inaccurate connection of the entropy to the number of collisions and intra-molecular interactions.*
- *Inaccurate connection of the entropy of the system and the entropy changes accompanying in the surroundings.*
- *Entropy of the whole system decreases/does not change when a spontaneous change occurs in an isolated system.*
- *Entropy of carbon dioxide is bigger than that of propane at the same temperature.*
- *Entropy of carbon dioxide and propane is the same at the same temperature.*

It is apparent that a major difficulty in entropy is the students' confusion of visual disorder and entropy. This most probably comes from the analogies used during teaching and also the definitions made and analogies used in textbooks. Some of the misunderstandings seem to have originated from incorrect transformation of the macro-world to the micro-world of particles in spite of the fact that particles in the micro-world have been introduced for easier understanding at the level of sensation as Krnel *et al* (1998) argue. Few students were aware of the definition of entropy; that it is the measure of the number of ways that energy can be shared among the particles. In addition, only a few students were aware of the microstates which are the possible ways of arrangements of particles. The previous studies by Selepe and Bradley (1997), Ribeiro (1992) and Ribeiro *et al* (1990) also support the findings of this study. It appears that teaching entropy as '*a measure of disorder*' is more likely to confuse students and cause misunderstandings as discussed in section 6.2.8.

9.1.4 Misunderstandings about Gibbs energy and related ideas

Many undergraduates who took part in the research were unwilling to answer the questions which related to Gibbs energy because of their lack of knowledge of the idea. Also the interviews which supported the questionnaire data demonstrated that students have little or no understanding of Gibbs energy. The most common misunderstanding was the confusion of thermodynamics data and kinetics data. Students were more likely to use thermodynamics data to make an estimation about the kinetics of a chemical reaction. The essence of the Gibbs energy was also missing. Students were only able to repeat the few facts that they had memorised but failed to apply them to problems which required understanding. The misunderstandings identified can be summarised as follows:

- *Gibbs energy increases in a spontaneous reaction.*
- *The slower the reaction, the smaller change in Gibbs energy.*
- *The bigger the Gibbs energy change, the faster a reaction occurs.*
- *The smaller* $\Delta_r G^\theta$*, the faster the reaction occurs.*
- *The bigger* $\Delta_r G^\theta$*, the faster the reaction occurs.*
- *The reaction with bigger* $\Delta_r G^\theta$ *goes towards full completion.*
- *If a reaction occurs fast, it goes towards full completion.*

The students' ability to apply of conceptual understandings to problems requiring diagrammatic representations was found to be very low. In a question called *Gibbs Energy* (see Appendix 8) eight different types of incorrect drawings were detected (see section 7.3). Overall, it can be said that students' understanding of Gibbs energy is vague due to the lack of encouragement for conceptual understanding and lack of prerequisite knowledge in order to understand the Gibbs energy idea.

In the following section the possible sources of the misunderstandings are discussed.

9.2 The Possible Sources of the Misunderstandings

This section summarises the possible sources of the misunderstandings in order to answer the second research question. Various reasons were considered as possible sources of the misunderstandings. These can be grouped into the following recurring themes:

(a) lack of knowledge of fundamental thermodynamic ideas, (b) application of algorithms without conceptual understanding, (c) using thermodynamic data to explain situations involving kinetics, (d) memorisation of scientific laws and statements without understanding, resulting in inappropriate over-generalisation, (e) confusion of fundamental ideas, (f) defining fundamental ideas according to their usage in everyday language, (g) the effects of everyday experiences, and (h) socio-economic and methodological aspects of the teaching and learning environment. These broad themes are discussed in detail in the following sections.

9.2.1 Lack of knowledge of fundamental thermodynamic ideas

Many students lacked knowledge of, or failed to apply, fundamental thermodynamic ideas in the questions associated with the ideas. Firstly, defining and differentiating the gravitational potential energy and coulomb (electrostatic) potential energy was especially difficult for the students. As discussed in section 4.1.6, when students were asked about potential energy almost all of them defined it as gravitational potential energy and therefore failed to apply it into the problem associated with coulomb (electrostatic) potential energy. It emerges that more importance should be given to the importance and use of coulomb (electrostatic) potential energy in chemistry.

Secondly, it was found that students' lack of knowledge of kinetic molecular theory and kinetic energy caused misunderstandings. This is particularly important for undergraduates, because it has been found previously from cross age studies that students at every level have difficulties with particulate nature of matter and kinetic molecular theory (Benson *et al* 1993, Novick and Nussbaum 1978,1981). It is possible to carry these misunderstandings into higher levels. This prevents the assimilation of new ideas. As Cornely-Moss (1995) argues it is important to start from the kinetic molecular theory in order to prevent misunderstandings about kinetic energy and particulate nature of matter.

Thirdly, it was also found that the lack of pre-requisite knowledge causes misunderstandings. For instance, it appeared that the students' lack of knowledge of potential and kinetic energy promoted misunderstandings about internal energy as it is the sum of kinetic energy of all particles and potential energy arising from their interactions with one another.

Finally, many students did not understand the essence of the enthalpy, entropy and Gibbs energy and displayed misunderstandings as discussed in the relevant sections. In addition, students who knew something about the ideas failed to apply their knowledge to the special problems associated with the ideas.

9.2.2 Application of algorithms without conceptual understanding

On several occasions students tried to answer the questions by using algorithms without a conceptual understanding. These attempts are displayed and discussed in sections 4.2.8, 4.3.1, 4.3.3, 4.4.2, 6.2.5. The majority of the applications of algorithms were seen as using some equations to answer the questions. There have been discussions in the literature that novice learners in chemistry and physics are able to apply algorithms without a significant conceptual understanding (Pushkin, 1998). It is argued that novice learners tend to be more declarative and procedural in their knowledge orientation. This means that novice learners tend to be very adept with arbitrary facts and generalised algorithms, and they rarely think in terms of integrated or applied knowledge (Pushkin, 1998). Students' habit of using algorithms to solve problems may be due to the temptation to be more declarative in their knowledge orientation and may also be due to the unintended impression that science is sort of mathematics, 'math in disguise', unintentionally caused by science teachers as Pushkin suggests. Pushkin also argues that science curricula discourage critical and conceptual thinking. Also, algorithms are fostered by the instructors by placing more value on algorithmic learning than on conceptual learning. This study provides evidences that students are more likely to use algorithms than conceptual understanding because of the importance given to algorithmic learning as discussed in Chapter 8.

9.2.3 Using thermodynamic data to explain situations involving kinetics

Confusion of kinetics and thermodynamics was a major source of the misunderstandings identified in this study. Questions which related to the enthalpy such as *Two Hypothetical Reactions*, Gibbs energy such as *Transformation of Diamond to Graphite* and *Two Spontaneous Reactions* displayed plenty of evidence. Students displayed difficulties in differentiating the kinetics data and thermodynamics data. As discussed in the related sections,

5. 4.10, 7.1.3 and 7.2.5 students attempted to use thermodynamic data to explain the kinetics of a chemical reaction. The work undertaken by Thomas (1997) also supports these findings.

9.2.4 Memorisation of scientific laws and statements without understanding, resulting in inappropriate over-generalisations

The misunderstandings discussed in section 5.1 provide evidence that memorisation without understanding causes misunderstandings such as confusion of lattice enthalpy with sublimation and formation enthalpy, and hydration enthalpy with activation and ionisation enthalpies. In addition, as discussed in section 7.1.3, students memorised some facts about Gibbs energy but did not understand the Gibbs energy at all. Moreover, students tended to make over-generalisations of principles and apply them regardless of thinking of the constraints as discussed in section 5.4.10. For example, none of the students were aware of the fact that if $\Delta G < 0$ a chemical reaction occurs spontaneously is only true under isothermal conditions and constant pressure. Granville (1985) also reports similar sources of misunderstandings.

9.2. 5 Confusion of fundamental ideas

There was confusion amongst the fundamental ideas for many students. The most common were between: real gas and ideal gas, dissolving and dissociation, heat and temperature, system and surrounding, and entropy and disorder. In addition, students also showed confusion about ΔH and enthalpy and similarly ΔG and Gibbs energy. Thomas (1997) also identified similar kinds of confusion amongst undergraduates. For example, 44% of his subjects confused ΔG, which is the change in Gibbs energy between two states, and Gibbs energy itself. It was observed throughout the interviews that students' responses displayed confusion of the energy changes at standard states such as ΔG^θ with the energy changes such as ΔG. These two ideas are different from each other, but students quite often use them interchangeably.

The confusion of real gas and ideal gas cases was identified in questions related to internal energy (see Chapter 4). These misunderstandings may arise due to either confusion or ignorance of the differences between ideal gases and real gases. In chemistry almost all the theories are based on ideal gases but things are different in real gas cases. For the undergraduates it is important to be aware of this fact, but this study provides evidence that students have problems in differentiating ideal gases and real gases. In addition, it was also observed that a few students had difficulty in differentiating dissolving and dissociation (see section 5.1). Moreover, the confusion of heat and temperature was identified in few of the responses as discussed in section 5.4.8. The most important confusion observed during interviews was the interchangeable use of heat and temperature. Similar findings are also reported in the literature such as Brook *et al* (1984,1985). Finally, students were confused about system and surroundings and entropy and disorder. They thought of disorder as visual disorder or as chaos from a macroscopic viewpoint as discussed in section 6.5.

9.2.6 Explaining fundamental ideas according to their usage in everyday language

There is no doubt that everyday language plays a vital role in students' misunderstandings. It is also seen as a major source of students' difficulties in this study. For example, quite often students appeared affected by the everyday meaning of the scientific ideas. This was apparent in the case of entropy. As discussed throughout Chapter 6, students' understanding of the word '*disorder*' reflected its everyday meaning such as randomness or chaos. In addition, similar reflections were identified in the case of '*spontaneity*'. Students' definitions and use of the term seemed to be affected by its meaning in everyday language as discussed in section 5.4.6. There is a great deal of agreement in the literature that the word 'spontaneous' itself causes misunderstandings because of its meaning in everyday language and in science (Ribeiro, 1990) and (Ochs, 1996).

9.2.7 The effects of everyday experiences

Students' everyday experience also has a great importance in teaching and learning. As discussed in section 7.2.5, students used the rusting of iron to back their arguments. They displayed misunderstandings about the Gibbs energy and also the use of thermodynamic data to explain kinetics of a reaction. In addition, the misunderstanding that *endothermic reactions cannot be spontaneous* may also result, as Johnstone *et al* (1977) argue, from the everyday observation that in spontaneous changes there is a tendency to minimise the energy. Moreover, confusion of microscopic state and macroscopic state may have roots in students' everyday experiences and observations.

9.2.8 Socio-economic and methodological aspects of the teaching and learning environment

As discussed throughout Chapter 8, socio-economic and methodological aspects of the teaching and learning environment have a great importance in learning. By socio-economic aspects, I mean the cultural and economic conditions which students and lecturers are in, and physical conditions of the teaching and learning environment. By the methodological aspects I mean the issues related to strategies that should be followed for better teaching such as using different teaching methods supported by various teaching aids, promoting conceptual understanding and motivating students etc. It was found from the student and lecturer perspectives on learning difficulties that students' backgrounds, their economic freedom, lack of resources and overcrowded classes were seen as major sources of students' learning difficulties. In addition, it also appeared that students were not happy with the teaching strategies applied in class and saw them as a vital source of learning difficulties. Although there were some discrepancies between lecturer and student perspectives on learning difficulties, there are some points where their perspectives overlapped, such as in expressing concerns about overcrowded classes and lack of resources.

9.3 Implications for Teaching

The results of this study suggest that many students in an advanced undergraduate class have difficulties in acquiring some the most basic chemical ideas as well as having difficulties in acquiring advanced thermodynamics ideas. Conversations with colleagues at other institutions of higher education suggest that it is likely that many of these misunderstandings identified in this study would be found among physical chemistry students in general, although the students in this study were from only two chemistry departments in Turkey. Therefore, the findings of the present study may provide some clues about the quality of student learning in typical physical chemistry classes.

Constructivist theories of knowledge are based on a fundamental assumption that knowledge is constructed in the mind of the learner (Driver, 1989). This suggests that students construct their own meaning by assessing and assimilating the new knowledge to that which they already have. Therefore students' previous knowledge plays a vital role in learning. Physical chemistry lecturers sometimes overestimate their students' understanding of basic ideas. If lecturers recognise the possibility of misunderstandings or no understanding concerning fundamental ideas, they will be better able to organise the teaching and learning environment by addressing and attempting to overcome student misunderstandings (Thomas 1997). As Ribeiro (1992) points out, university lecturers would provide better teaching if they begin with the question '*what do students see, do and know?*'. Discussion of students' ideas amongst themselves and with lecturers may bring out what they already know and do not know and may provide a way forward for better teaching. Beall (1994) argues that informal in-class writing also provides clues to students' previous knowledge. Overestimating students' previous knowledge and misunderstandings makes the difficulties even more chronic.

In order to improve the students' understanding of important thermodynamic ideas lecturers might concentrate more on the quality than the quantity of material covered during the course, as Thomas (1997) points out. In doing this, some of the students may need extensive help to change their way of thinking about fundamental ideas and replace incorrect beliefs with the scientific ones. Otherwise, if student misunderstandings are not addressed by the lecturers, students might continue to hold them even if they successfully complete the requirements of the course. In addition, as Pushkin (1998) argues, exposure to many ideas at a time promotes memorising and enhances algorithmic skills instead of conceptual learning.

Since this study provides evidence that students' explanations of scientific phenomena are based on the macrophysical world and they have a very limited level of microscopic level thinking, lecturers should check that students have acquired the correct scientific meanings of ideas taught and that they can apply the ideas learned in different situations, whether it is an everyday phenomenon or theoretical one (Selepe and Bradley, 1997). In addition, university lecturers should pay attention to everyday, out-of-class ideas associated with the scientific terms they use. They should also be checking if students have understood in the way they intend Ribeiro (1992). As Ribeiro *et al* (1990) argue the best way of becoming aware of the shortcomings of one's own knowledge is to rub it up against that of others. Discussions with students may provide a better chance of knowing their shortcomings.

In order to overcome the difficulties of confusion among ideas, students might be helped to see clearly the contextual differentiation of their knowledge. As discussed in section 9.2.5, this is a major source of students difficulties. It was argued by Ramsden (1997) that a context based approach, using scientific applications and context as a starting point, in teaching may provide better help for students in developing an understanding of some areas of chemistry as compared to traditional approaches. In addition, as Carson and Watson (1999) point out, it is important that thermodynamic entities are defined qualitatively and their effects talked about before they are defined quantitatively. Therefore, it is suggested that there is a need to reverse the usual procedure where numerical problem solutions are set first and then understanding follows. The results of this study support Carson and Watson's (1999) findings that students were not able to draw out the meaning attached to the thermodynamic entities defined quantitatively, therefore teaching thermodynamics requires new perspectives rather than traditional teaching methods. It is evident from the literature that traditional teaching methods are ineffective in tackling the students' misunderstandings (Bodner, 1991).

Finally, as Millar (1989) argues *'the process of eliciting, clarification and construction of new ideas takes places internally within the learner's own head,... science should be taught in whatever way is most likely to engage the active involvement of learners*' (p.589). Conceptual learning can be fostered by providing students with a variety of learning experiences.

9.4 Reflections on the Study

This study aimed to identify and classify chemistry undergraduates' misunderstandings of thermodynamics ideas such as internal energy, enthalpy, entropy and Gibbs energy, together with the sources of these misunderstandings. Some aspects of the study were more successful than others at answering the research questions. The aspects of the study which provided informative answers were identification and classification of chemistry undergraduates' misunderstandings in the selected topics, in response to the research question one which states; *'What are the third year Turkish chemistry undergraduates' misunderstandings about internal energy, enthalpy, entropy and Gibbs energy?'.*

It is thought that, however, the second research question, which states *'Where do these misunderstandings arise? What are their sources?'* has been less fully explored. It is recognised that there is an inherent difficulty in identifying the sources of students' misunderstandings in this type of research, because the sources of students' ideas cannot be easily classified. Several factors contributing to learners' learning such as the learners' brain structure, experience of the world, the effects of language, out of school experiences, and classroom experiences may play a part in building up new ideas. As learning is accepted as being a personal construct by constructivists, a failure at any stage of this construction may cause misunderstandings. It is not possible to find out easily why misunderstandings occur. The studies in this area have broadly focussed on cataloguing misunderstandings in various subject areas and different levels and in exploring the characteristics of misunderstandings rather than their sources. The review by Wandersee *et al* (1994) argues that the origin of misunderstandings remains speculative, because the evidence for the origins of misunderstandings is often inferential at best, and certainly such origins are difficult to document (p.188). They argue that this view is especially true for misunderstandings derived from direct observation and perception, where the primary data is often statements of self-report by the subjects involved.

In the light of this discussion, therefore, it must be accepted that the attempts made to answer the second research question were inadequate. Only limited information on the sources of the undergraduates' misunderstandings was obtained from the data presented in Chapters 4,5,6,7,8. It is acknowledged, in retrospect, that the results presented in Chapter 8 focus on students' and lecturers' perspectives on students' learning difficulties of chemical ideas in thermodynamics and some proposed solutions to these difficulties. It is also acknowledged, in retrospect, that the second research question was not appropriately formulated. A more appropriate formulation of this question would have been *'what are the students' and lecturers' perspectives of students' learning difficulties of chemical ideas in thermodynamics'.*

Two aspects of the study where improvements could have been made are:

(a) an alternative way of analysing the data.

(b) a critique of diagnostic questions and possible improvements.

Each of these will be considered in more detail in the next sections.

9.4.1 An alternative way of analysing the data

This section aims to illustrate an alternative to the analysis already carried out. The data analysis method employed, which is based upon question by question analysis, has been successful in identifying and cataloguing the students' misunderstandings. However, it does not provide any evidence as to whether these misunderstandings are individual cases or students hold a relatively stable alternative framework that applies in different contexts. This could be approached by an alternative analysis that looks at the responses to a range of questions given by a set of individual respondents.

While there does seem to be widespread support for the notion that students construct beliefs about many science phenomena, the techniques used to identify these vary considerably (Driver and Erickson, 1983). It is apparent that this diversity results in some confusion as to how widespread misunderstandings are, and how these misunderstandings affect each other. As Driver and Erickson (1983) suggest, the confusion stems in part from the unit of analysis adopted by researchers to define student frameworks. Some researchers define frameworks as individual constructs, whilst others have described them as 'a composite picture based upon ideas shared by a number of pupils' (Driver and Erickson, 1983, p.46). Different views on the nature of students' understanding, and differences in the methodologies employed to discover students' conceptions led researchers to make different claims. One of the widely discussed theories in science learning is that *'children's conceptions are genuinely 'theory-like', that is having a coherent internal structure and being used consistently in different contexts.'* (Driver, 1989; p.483). This notion is articulated by McCloskey (1983) and supported by Engel Clough and Driver (1986). McCloskey argues that people develop well-articulated naive theories on the basis of their everyday experiences. Furthermore, he argues that these naive theories are consistent across individuals.

On the other hand, diSessa (1988) raises issues to do with the nature of misunderstandings. He questions the views of McCloskey (1983) and argues that people hold loosely connected, fragmented ideas, some of which reinforce each other but none of which have the rigour of theory. In diSessa's words students have 'knowledge in pieces'. diSessa goes on to suggest that there is evidence in his work of students making up explanations spontaneously at the point which they are faced with a question, drawing where they can on core intuitions based on everyday experience. (He calls these notions phenomenological primitives, or p-prims). Later work, for example that of Southerland *et al* (2001) provides additional support for the notion that students make up explanations spontaneously. Therefore students' explanations may not be misunderstandings, rather they are spontaneous constructions which might be scientifically correct or incorrect. Southerland *et al* (2001) also argue that, if it is accepted that some students reason from core intuition, a great deal of variability in students' explanations is to be expected.

In the light of the above discussions, the following possibilities can be considered in the present study. Students may have:

a) isolated misunderstandings

b) a fragmented pattern of misunderstandings

c) a systematic pattern of misunderstandings (i.e. an alternative framework).

There is also another possible category concerning students' spontaneous reasoning from core intuitions. However, this aspect is likely to be most effectively explored through interviews, and the written diagnostic questions used in this study cannot yield information on spontaneous reasoning. This discussion therefore focusses on categories a, b and c outlined above.

This study provides many examples of (a), with isolated misunderstandings being evident in the detailed examination of the data for the group as a whole.

In this section, a limited analysis of existing data on how individual students answered questions on a particular topic is undertaken to look for any possible patterns in the students' responses and identify if there is any evidence of (b) or (c).

Two aspects of the data may provide evidence of possible patterns in an individual's responses. The first is the stability of students' misunderstandings over time and the second stability of misunderstandings over different task contexts. Studies have been carried out to show whether a particular type of misunderstanding is stable over time, for example cross-age studies of Novick and Nussbaum (1981) and more recently Southerland *et al* (2001). These studies suggest that students' misunderstandings are persistent. Also, some studies have investigated the consistency in students' responses across task contexts, such as that of Engel and Driver (1986) and Schmidt (1997). These demonstrated that students have misunderstandings in every concept which was investigated, but at an individual level, these misunderstandings did not constitute an alternative framework.

In the present study, a limited number of comparisons was carried out to investigate the extent of consistency and change in students' responses over time by comparing pre-test and post-test responses (see sections 4.6, 5.6 and 7.4). The results suggest that, in general, there is no apparent change in the nature of students' misunderstandings before and after teaching, although the number of students who attempted to answer the questions at post-test increased for some questions.

No comprehensive attempt was made to investigate the stability of students' misunderstandings in different task contexts. This could be done by looking at individual students' responses to different questions to see if these provide evidence of a fragmented pattern of misunderstandings or a systematic pattern of misunderstandings (i.e an alternative framework) applied across different contexts at an individual level. In order to achieve this, a small scale analysis was carried out comparing the responses of five students to three post-test questions on internal energy. For this alternative analysis, the questions related to internal energy were chosen for three main reasons. Firstly, the questions related to internal energy were the least conceptually demanding of the four ideas investigated. These questions focussed on comparatively simple ideas and were therefore attempted by more students. Thus they provided more data to probe for evidence of patterns in misunderstandings. Secondly, the ideas were explored in several questions in order to probe understanding in different contexts. Thirdly, the questions related to internal energy generated a range of responses. This was particularly the case in post-test-II, and for this reason the three questions on internal energy in post-test-II were selected for this analysis .

For this alternative analysis, the following procedure was adopted to identify the sample of students to be used. All the students response categories in post-test-II were tabulated for comparison. Five students who consistently displayed misunderstandings in their responses to the three questions were then selected at random. The categories into which these students' responses were placed are tabulated in Table 9.1.

Table 9.1 The categories of the selected students' responses

Student Code	**The name of Question**		
	Potential Energy	*Perfect Gases*	*Water*
$ST_2/B/S_5$	40	40	40
$ST_2/B/S_9$	60	30/40	40
$ST_2/B/S_{11}$	30/40	40	30/40
$ST_2/E/S_3$	00	40	30
$ST_2/E/S_{16}$	50	40	30/40

***Note:** The codes in Table 9.1 stands for; **30** (Understanding of only some aspect/s of the specific chemical idea tested in the question), **40** (Evidence for misunderstandings relating to the specific chemical idea tested in the question), **50** (Evidence for misunderstandings relating to general chemical / scientific knowledge) and **60** (Sound understanding of the specific chemical idea tested in the question).*

The responses are now considered in detail to see if there is any evidence of a systematic pattern of misunderstandings or whether there are different misunderstandings in different cases.

In the case of student $ST_2/B/S_5$, it seems that there is a similarity in reasoning. The reasoning is based upon two variables, movement and collisions of molecules. For example, the student answered the question 'Potential Energy' in terms of movement.

> *It is assumed that ideal gases move at maximum velocity. Therefore their kinetic energies will be maximum. If kinetic energy is maximum then potential energy has to be minimum.*

The student's answer to the second question 'Perfect Gases' shows a reasoning based upon the collisions of molecules:

> *Internal energy decreases because the number of collisions of gas molecules with each other and the walls of container decreases.*

Finally, the answer to the question 'Water' is also based upon the movement of molecules:

> *The movements of water molecules increase in the first beaker because of the increase of heat. Therefore their internal energies increase.*

As can be seen from the three responses above, the respondent tries to relate his/her reasoning to the movement and collisions of gas molecules. The responses do not constitute an accepted response to the questions and they include misunderstandings such as *'potential energy of ideal gases is zero because ideal gases have maximum velocity'* and '*internal energy of perfect gases increases/decreases if the number of collisions of particles increases/decreases in isothermal conditions*'. However, there is no evidence to suggest that these misunderstandings form a particular framework in the respondent's mind, although there is a similarity in the way that the respondent approaches the questions. The responses seem fragmentary and only loosely connected. This seems to correspond to category (b), a fragmented pattern of misunderstandings.

For student $ST_2/B/S_9$, the response to the question 'Potential Energy' was coded as sound understanding. The response to the second question, 'Perfect Gases' includes both partial understanding and misunderstanding. Finally, the response given to the question 'Water' shows misunderstanding. The responses are as follows:

Response to 'Potential Energy':

> *Potential energy of ideal gases is assumed as zero because they are accepted as dot like particles and their specific volumes are negligible. It is assumed that the ideal gas molecules do not have intermolecular interactions. Potential energy is emerged from the intermolecular interactions like repulsions and attractions. If there is no interactions there is no potential energy.*

Response to 'Perfect Gases':

> *Internal energy is the heat exchanges at the constant volume. In this questions, the volume has changed but temperature is kept constant. Therefore internal energy does not change.*

The response to 'Water':

> *In the first beaker heat is increased, in the second beaker the movement of molecules are increased. Internal energy does not change.*

From the first response it is clear that the student has a sound understanding of potential energy. From the second response, it appears that the respondent has some knowledge of internal energy, because it was attempted to state the fact that '*internal energy change is the energy transferred as heat under the constant volume*'. However, it appears that the respondent cannot use this information in solving the problem and incorrectly reasons that internal energy does not change because volume has changed but temperature has been kept constant. The third response does not include any part of an accepted response but displays the misunderstanding that '*internal energy of a system does not change by doing work on or transferring energy as heat in it*'. In this student's case none of the responses seem to be related to each other, every response stands alone. These responses indicate that there may at best be a fragmented pattern of misunderstanding or the misunderstandings displayed are merely isolated cases. The respondent has some knowledge of each idea (some of which are incorrect) but is not able to link them together. Similarly, respondents $ST_2/B/S_{11}$ and $ST_2/E/S_3$ also showed no pattern in their responses. Their responses to the three questions displayed both partial understandings (30) and misunderstandings (40), but these responses did not display any evidence of a pattern.

Respondent $ST_2/E/S_{16}$ showed similar ways of reasoning to student $ST_2/B/S_5$. In this case, the respondent tried to attribute the changes to possible variables such as temperature and volume. For example in the response to 'Potential Energy' the respondent argues that:

> *Ideal gases are gases at high pressures and low temperatures. Since potential energy is related to temperature and the temperature of ideal gases is close to zero, potential energy of ideal gases is assumed as zero.*

The respondent showed a similar way of reasoning in the second question 'Perfect Gases' attributing the changes to a system variable, which in this case, is volume change as seen from the quotation below:

> *Internal energy is related to volume and temperature. Since the volume increases internal energy increases.*

The two responses quoted above display a certain way of reasoning, i.e. attributing any change to the variables given in the question, in this case temperature and volume. Such responses were common in responses to the questions, with many students tending to offer explanations only in terms of the variables given in the question. This may suggest that students' reasoning is limited and restricted to the information in the question. They cannot inter-relate ideas from different sources and make a judgement based on these. They cannot establish connections between the pieces of knowledge they have and they can only consider each piece in its own context, indicating fragmented patterns of knowledge and misunderstandings (b).

From this small scale cross-question analysis the following conclusions may be drawn. Firstly, students have misunderstandings almost in every idea investigated in this study. This is widely evidenced throughout the thesis and misunderstandings are documented and discussed in detail.

Secondly, when individual students' responses were examined, the results suggest that students hold loosely connected, fragmented knowledge about the ideas tested. Some respondents show some evidence of patterns in their reasoning to related questions but there is little evidence of consistent conceptual frameworks underpinning the misunderstandings. The results of this small scale cross-question analysis are in line with those of Engel and Driver (1986) who demonstrated that students had misunderstandings in almost every concept which was investigated, but at an individual level, these misunderstandings did not constitute an alternative framework. However, it should be borne in mind that the analysis reported in this section represents only a small sub-set of the data collected and a more extensive analysis would be required to confirm this preliminary finding.

Finally, this small-scale analysis allows some tentative suggestions to be made for the data as a whole. It seems reasonable to suppose that a similar cross-question analysis of other content areas, such as enthalpy, entropy, and Gibbs energy, is unlikely to reveal the existence of alternative frameworks. Furthermore, it is also seems reasonable to propose that the chances of finding evidence of alternative frameworks existing will become less likely as the conceptual demand increases. The internal energy questions were selected for this small-scale analysis because they were less conceptually demanding and therefore attempted by more students . Thus they provided more data to probe for evidence of patterns in misunderstandings. No evidence was found to support the existence of alternative frameworks although the results suggest that the nature of students' understandings has fragmented patterns. These fragmented patterns of understanding are less likely to act as an adequate basis for building up ideas and students will therefore be less likely to develop coherent frameworks (whether correct or incorrect) for more conceptually demanding ideas.

9.4.2 A critique of diagnostic questions and possible improvements

Although the questions were piloted and necessary modifications made, students still found it difficult to understand the content of some of the questions. Some students also appeared to have difficulties in understanding the illustrations in the questions. These difficulties were supported by anecdotal evidence from students after they had completed the questions. The majority of the questions yielded a range of responses and produced consistent response types in the pre and post-test. However, some of the questions were less effective than others in revealing students' misunderstandings. In this section, the questions which appeared to be effective in diagnosing students' misunderstandings and those which appeared to be less effective will be discussed in detail. The section also includes suggestions for improving some of the questions in this latter group.

In the questionnaire, diagnostic questions were used to explore students' understandings of four chemical ideas in physical chemistry prior to teaching and after teaching. The preparatory reading for this study has led to the conclusion that a good *diagnostic question* is one which generates information which accesses respondents' thinking about the ideas being explored. As discussed in section 3.3.1, the questionnaire contained two types of diagnostic questions.

These are '*recall questions*' which were intended to test students' knowledge of the ideas investigated and '*understanding questions*' which were intended to test students' understanding of the ideas taught. Six recall questions such as 'Potential Energy', 'Helium and Carbon Dioxide', 'Explosion in a Steel Box' and 'Spontaneous Change' were designed for this purpose. Eleven understanding questions such as 'Energy', 'Two Hypothetical Reactions', 'Magnesium', 'Gibbs Energy' and 'Ice Melting' focussed on students' understanding of the ideas.

In designing diagnostic questions, the following points were considered:

- One particular idea should be addressed in each question or sub-question.
- The questions should be structured so as to probe understanding in detail.
- The structure, wording and layout of the questions should be clear and be easily understandable.
- The questions should address core chemical ideas in thermodynamics.
- If a diagram or illustration is required to facilitate students' understanding of a question, it should be simple and illustrative.

In the next paragraphs the questions thought to be effective or less effective in diagnosing students' understandings in the subject tested will be discussed in terms of how well they fulfill the features of diagnostic questions outlined above.

It was considered that only one particular idea should be addressed in each question to facilitate the analysis of written responses. In this respect, the questions fulfilled this criterion. However, there were some difficulties in analysing the responses given to the questions which contain sub-questions such as 'Mixing of Gases' and 'Copper (II) Sulphate'. In these questions some of the sub-questions were intended either to determine if students applied the same idea in different situations, as was the case in 'Mixing of Gases' or test different aspects of the same idea, as it was the case in 'Copper (II) Sulphate'. One of the weaknesses that emerged from this type of question was the range of responses which each sub-question generated. Some of the sub-questions were answered by most of the students, while some of them attracted responses from only a small fraction of the respondents. This problem was particularly associated with the content of the questions. Few students answered questions related to Gibbs energy. For example, in the question 'Mixing of Gases', 50% of responses to the 'sub-question **c**',which was related to Gibbs energy, were blank in the post-test. The percentages of blank responses varied for 'sub-question **a** and **b**' from 34% and 43% respectively. The high number of blank responses makes the question less useful in diagnosing students' misunderstandings and also reduces the possibility of comparing responses during analysis. In contrast, questions related to internal energy such as 'Helium and Carbon Dioxide', 'Potential Energy' and 'Perfect Gases' and related to enthalpy such as 'Energy' received a high number of student responses. These questions generated a range of responses revealing students' strengths and weaknesses in understanding the ideas investigated.

Another essential feature of the diagnostic questions was to probe understanding in detail. Broadly speaking, the questions fulfilled this aim, but some were more successful than others. In this respect, the question 'Energy' was considered to be one of the most effective diagnostic question to test students' understanding of the source of energy in chemical reactions as it revealed a number of misunderstandings. In addition, Copper (II) Sulphate was an effective question in revealing students' knowledge about enthalpy changes at different stages of a chemical reaction. Similarly, 'Two Hypothetical Reactions' , 'Helium and Carbon Dioxide' and 'Potential Energy' were also considered effective diagnostic questions. The main features of these questions was that they were answered by the majority of respondents and these responses included various explanations and approaches which helped to identify the nature of students' difficulties in understanding chemical ideas. On the other hand, other questions, such as 'Seawater', 'Mixing of Gases', 'Transformation of Diamond to Graphite' and 'Gibbs Energy' were thought less effective in fulfilling the aim of probing understanding in detail. In the pre-test, '*understanding questions*' generated few responses. In contrast, '*recall questions*' generated a broader range of responses. However, in the post-test the range of responses varied from question to question. There was some increase in the range of responses for understanding questions, such as 'Transformation of Diamond to Graphite' and 'Gibbs Energy'.

The structure, wording and layout of the questions were considered as important features of diagnostic questions. The questions 'Energy' and 'Helium and Carbon Dioxide' were designed in such a way that they tested the same idea twice in the same question. This was found particularly helpful in terms of identifying consistency in students' responses. There was some consistency in responses, but there were also numerous instances of responses which were inconsistent. For example, the same respondent displayed different reasoning in both sub-questions which tested exactly the same idea. This can be considered as evidence for a fragmented pattern of understanding (see section 9.4.1). In retrospect, it would be advisable to use this 'double check' mechanism in diagnostic questions, not only to get broad range of responses but also to be able to capture students' consistency of response. This could also be achieved by testing similar ideas in different questions.

The aspects of an idea tested in a diagnostic question is also considered as an important issue. Questions such as 'Explosion in a Steel Box', 'Ice Melting' and 'Water' which focussed on a narrowly defined specific aspect of a chemical idea were found less effective in diagnosing students' misunderstandings. In the case of these questions, the responses were short and included less 'explanation'. This makes it hard to reveal the nature of students' understanding of the aspect of the idea tested. In retrospect, it was recognised that the questions, which were intended to be diagnostic, might have been more successful if they had addressed core chemical ideas rather than a narrowly defined specific aspect of a chemical idea.

There were also issues concerning the diagrams and illustrations in the questions. On some occasions, understanding the diagrams seemed to cause difficulties for the students. For example, there was some anecdotal evidence and also it was evident from some of the responses that students did not understand the diagram in the 'Magnesium' question. In addition, it was realised that if there is a need for a diagram or an illustration to facilitate students' understanding of a particular question, the diagram should be presented to the students in a form with which they are familiar or it is likely to cause confusion. This was evidenced in some responses given to the question 'Copper (II) Sulphate' (see section 5.1.3.2). The way that the energy level diagram was presented was not familiar to the students in one of the participating departments. In this case, students had difficulty in understanding the energy level diagram. As a result, it can be concluded that diagrams or illustrations should be familiar to the students. Also, they should be as simple as possible and not include too many complex drawings and signs.

Finally, as a result of reflecting on the study, the following recommendations can be made to improve the effectiveness of the diagnostic questions which appeared to be less effective in probing students' understandings and misunderstandings. In some questions either the content or the way in which questions were presented could have been changed. For example, students found questions 'Ice Melting' and 'Seawater' difficult to understand. It is probable that either the content of the questions or the way in which they were presented was less helpful in promoting understanding of the idea tested in the question. Therefore, the question 'Ice Melting' would have been improved by adding a simple diagram visualising the case. This might help students understand the problem more easily. In the case of 'Seawater', the subject matter of sub-question **b** was found to be particularly difficult to answer. This sub-question either could have been omitted or asked in an another context.

In some of the questions, providing examples with which students are already familiar may have improved the students' understanding of the question, and consequently the nature of students' explanations. For example, instead of using a beaker of water in the question 'Water', an example of the compression of a gas in a cylinder would help students to see that work has been done on the system by compressing the gas. Since students are more familiar with the examples associated with gases, they might have been in a better position to understand both the context and the question.

The diagrams in the questions could also have been improved. For example, in the question 'Magnesium' some students still found it difficult to understand the diagram despite efforts made to improve it. This diagram should be either transformed to a much more basic form or some explanations provided next to the diagram in order to help students to understand the case. Also the energy level diagram in 'Copper (II) Sulphate' could have been given in a way that students are familiar with. Finally, the question 'Gibbs Energy' could have been presented in a slightly different way to facilitate students' understanding. Providing the curve which represents the Gibbs energy change versus extent of a reaction on the graph and asking students to discuss Gibbs energy change on the different parts of the curve might have encouraged more students to answer the question.

9.4.3 A critique on the overall research strategy

As far as the overall research strategy was concerned, the following comments can be made. Firstly, in terms of the interview strategies followed, some improvements could have been made. The interviews in this study had to be carried out soon after the administration of the questionnaire because of the time restrictions on overseas data collection. Therefore, it was difficult to clarify some of the unclear responses later detected in the questionnaire data. If it had been possible to conduct the interviews after the analysis of questionnaire data they could have be more helpful in terms of clarifying student reasoning in various cases.

Secondly, focussing on only one or two ideas rather than studying a broad range of ideas would have provide an opportunity to delve further into the students' strengths and weaknesses in a particular idea. Finally, data collection from a broader sample of students in different institutions would have increased the richness of the data and its generalisability.

9.4.4 A Way Forward

A way forward would be the development of a more standardised diagnostic test, which should be easy to administer and evaluate and which can be used to investigate the conceptual understanding of larger samples. Additional studies are needed to verify and expand this study's compilation of misunderstandings in thermodynamics. Also, a representative sample of physical chemistry students from a wide variety of institutions should be included in these additional studies.

Once a diagnostic test has been developed that is both a valid and reliable measure of students' understanding of thermodynamic ideas then it can be used by the lecturers during teaching in order to diagnose students' misunderstandings and point to areas where remedial work may be useful.

Appendix 1

The Pilot Study Questionnaire-1

Name:______________

Date:_______________

Start Time:__________

Finish Time:__________

AN INVESTIGATION *of* UNIVERSITY STUDENTS' IDEAS ABOUT INTERNAL ENERGY, ENTHALPY, ENTROPY AND GIBBS FREE ENERGY

Time Required : Approximately 100 minutes

Before you start please read the letter on the next page.

Mustafa SOZBILIR

Department of Educational Studies
University of York
York YO10 5DD

Dear Student,

You may be wondering why you are being asked to complete this test!

I am a researcher working on a research project to find out university chemistry students' ideas about some aspects of chemistry. The study is taking place over three years. Similar tests will be given to the students who follow you to on the course. Your responses to the questions will help tutors and lecturers gain a better understanding of the ideas of the thermochemistry students find difficult.

The test is designed to reveal what chemistry students really understand. You are encouraged to put your own ideas. I am asking you to answer honestly. If you are not able to answer the question, don't panic! This is not an exam. You don't need to force yourself to give an answer. Don't look for tricks (none are intended) and lengthy answers are not expected.

The test may seem to be a lot of pages, but the print is big and there are lots of pictures and plenty of space. So, don't worry about the quantity of the pages!

If you are not able to give an answer to a questions pass on to the next one. Don't spend too long time for any one. 5 minutes should be enough for each question.

I would not be able to give an answer to any question asked in the test. If you enquire more about the answer, you may do a search for yourself or discuss with your lecturer. This is because of the confidentiality of the research study. I apologise for any inconvenience about this issue.

It would be great help to me if you could write the time you started and completed the test on the front cover. All the responses from you and information about you will be confidential and will only be used for the research study.

I am planing to interview a small group of students to gather more information on possible areas of difficulty. These interviews will be recorded for research purposes only. If you do not want to be interviewed, please tick the box here ☐.

Thank you very much for completing the test.

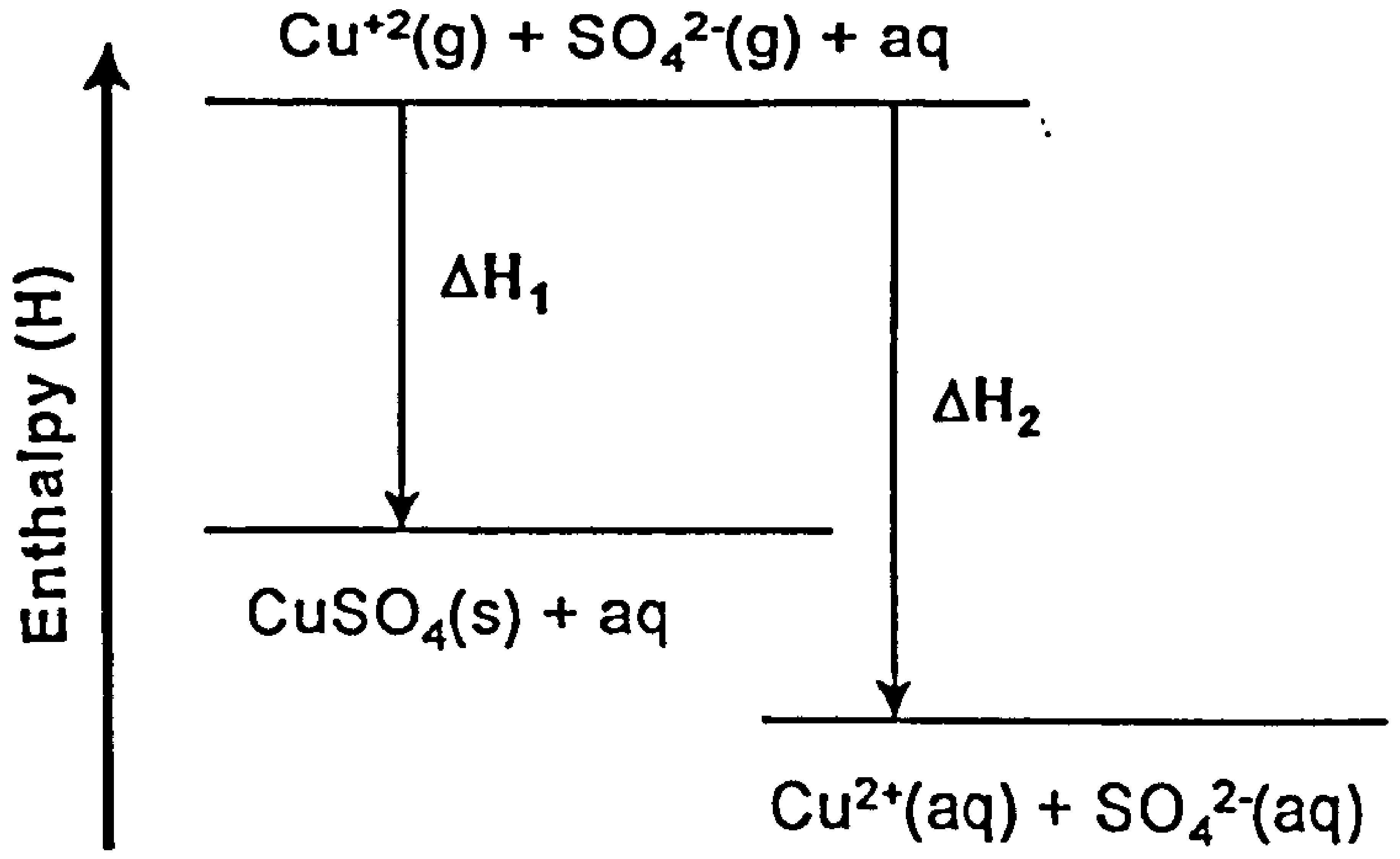
May 1998

Yours sincerely

M. SÖZBİLİR

Cupper (II) Sulphate

An energy-level diagram is shown below for the dissolving of anhydrous cupper (II) sulphate.



a) Choose terms from the following list to describe the enthalpy changes indicated by ΔH_1 and ΔH_2 in the diagram:

enthalpy of activation
bond enthalpy
enthalpy change of formation
hydration enthalpy
enthalpy change of ionization
lattice enthalpy

ΔH_1 is..., ΔH_2..

b) Draw an arrow on the diagram above to represent the enthalpy change of solution (ΔH_{soln}) of $CuSO_4(s)$.

c) Would you expect the temperature of the water to raise or fall when anhydrous cupper (II) sulphate dissolves? Explain your answer.

Helium and Carbon Dioxide

a)

Contains He
n = 1 mol
V = 1 L
T = 298 K

Contains CO_2
n = 1 mol
V = 1 L
T = 298 K

The two containers contain one mole of helium and carbon dioxide at the same temperature.

Tick the box you think true about average kinetic energy of the gases, and explain how you decided which box to tick.

☐ The average kinetic energy of helium is more than carbon dioxide.
☐ The average kinetic energy of helium is less than carbon dioxide.
☐ The average kinetic energy of helium is the same with the carbon dioxide.

Explanation:

b)

Contains He
n = 1 mol
V = 1 L
T = 298 K

A

Contains He
n = 1 mol
V = 0,5 L
T = 298 K

B

The two containers contain one mole of helium at the same temperature.

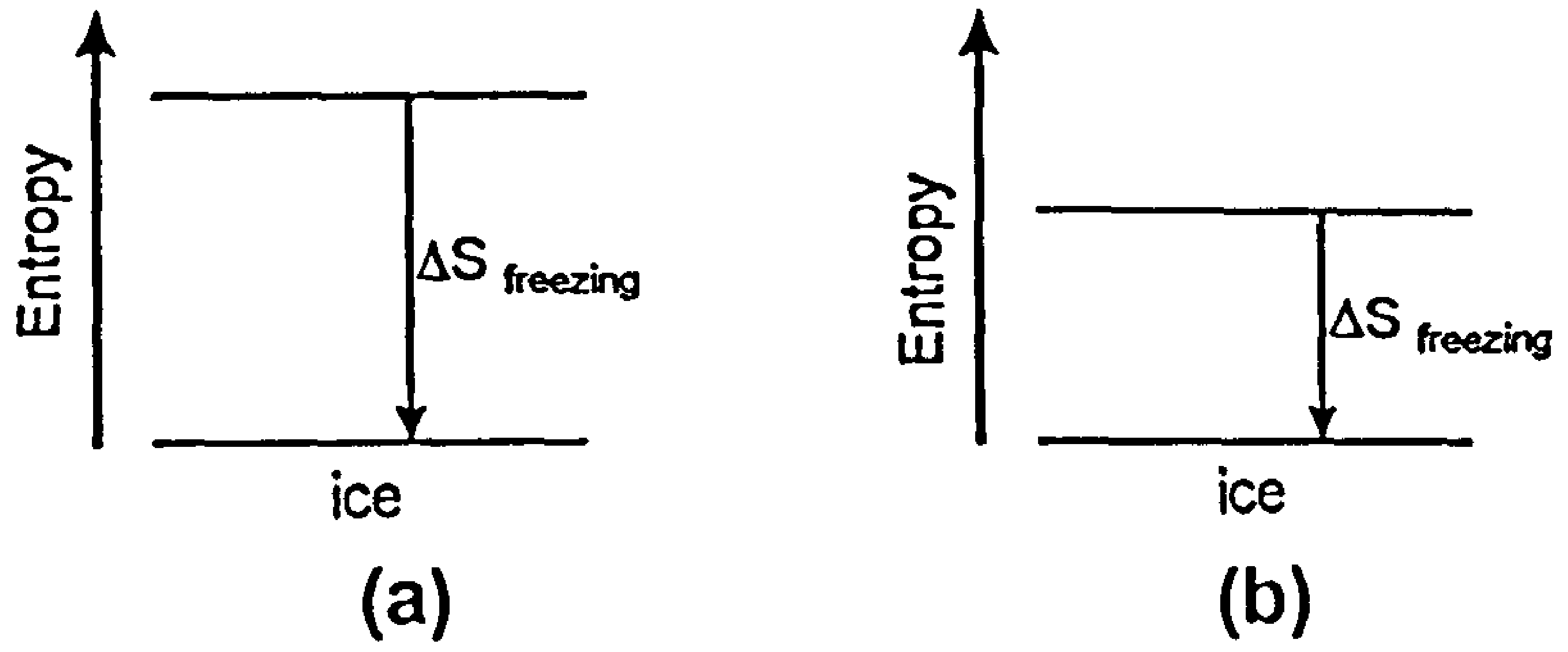
Tick the box you think true about their average kinetic energy, and explain how you decided which box to tick.

☐ The average kinetic energy of the helium in container A is more than that of in container B.
☐ The average kinetic energy of the helium in container A is less than that of in container B.
☐ The average kinetic energy of the helium in container A is the same that of in container B.

Explanation:

Seawater

Seawater contains different kinds of dissolved minerals, therefore freezes at a lower temperature than pure water. The released energy is the same when seawater and pure water freeze, but the entropy change of the system is different. Two diagrams below show the entropy change of the freezing seawater and the pure water.



a) Tick the box you think represents the entropy of the seawater when it freezes, and explain how you decided which box to tick.

☐ Diagram (a) ☐ Diagram (b)

Explanation

b) The entropy change of the freezing of pure water is:

$H_2O(l) \rightarrow H_2O(s) \qquad \Delta S = -22{,}0\ \text{kJ mol}^{-1}$

Using this information, tick the box you think true about the entropy change of the surroundings before the freezing can occur, and explain why?

☐ Before freezing can occur, ΔS_{surr} has to be more positive than + 22,0 kJ mol^{-1}.

☐ Before freezing can occur, ΔS_{surr} has to be less positive than + 22,0 kJ mol^{-1}.

☐ Before freezing can occur, ΔS_{surr} has to be + 22,0 kJ mol^{-1}.

Explanation

a) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l) \qquad \Delta H^\ominus = -286\ \text{kJ mol}^{-1}$

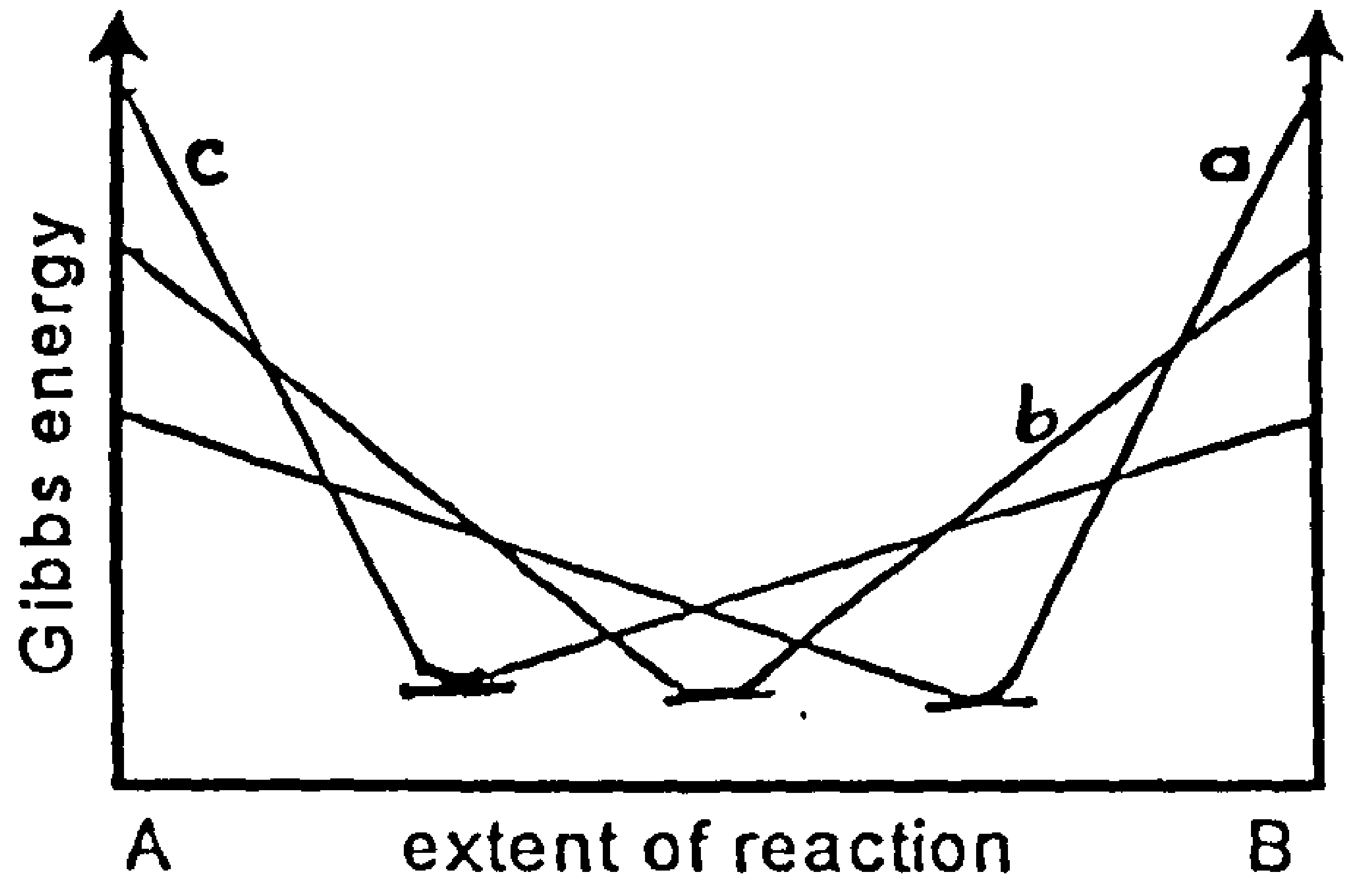
This thermochemical equation tell us that 286 kJ of energy are released when one mole of hydrogen molecules reacts with oxygen molecules to form one mole of water molecules.

Explain as carefully as you can why energy is released in this reaction.

b) $N_2(g) + 2\,O_2(g) \rightarrow 2\,NO_2(g) \qquad \Delta H^\ominus = 68\ \text{kJ mol}^{-1}$

This thermochemical equations tells us that 68 kJ of energy are required when one mole of nitrogen molecules react with oxygen molecules to form two moles of nitrogen dioxide molecules.

Explain as carefully as you can why energy is absorbed in this reaction.



The figure shows Gibbs free energy changes against extent of reaction for the reaction A $\rightleftharpoons$ B with different initial proportions of A and B. According to this figure which of the following statement are true ?

Tick the box you think true and explain how you decided which box to tick.

☐ Graph **'a'** shows that equilibrium lies close to pure A.

☐ Graph **'b'** shows that equilibrium corresponds to A and B present in similar proportion.

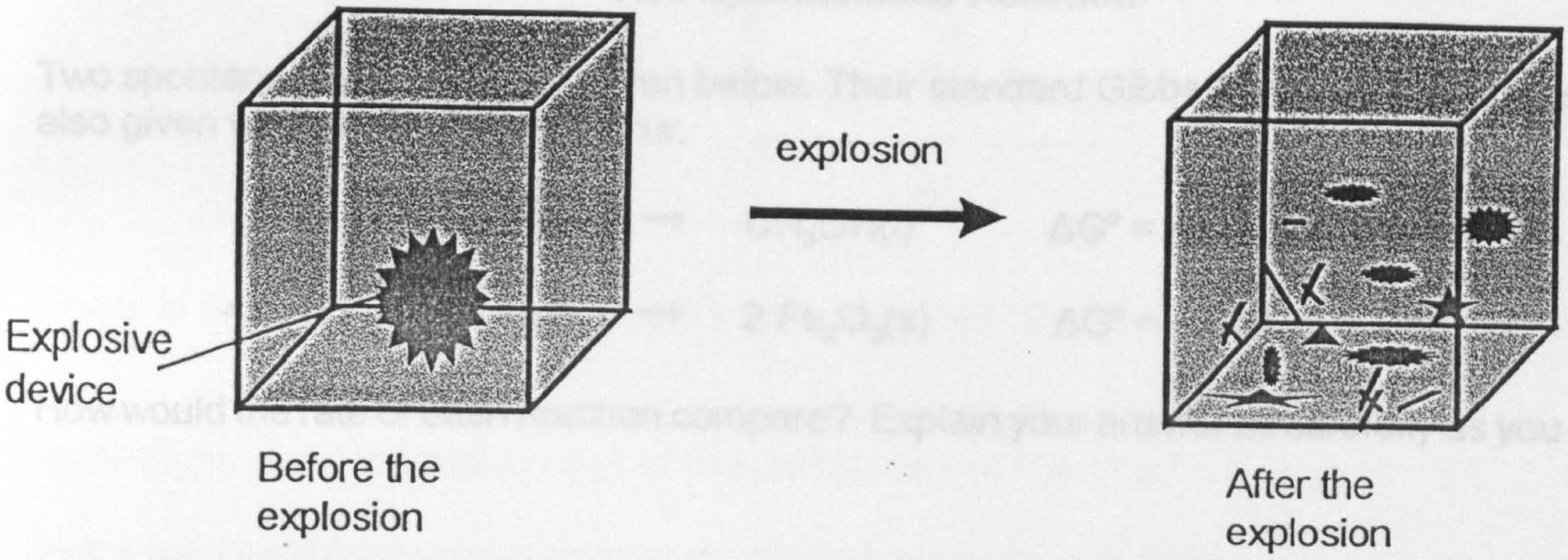
☐ Graph **'c'** shows that equilibrium lies close to pure B.

Explanation

Potential Energy

The potential energy of the perfect gas molecules assumed as zero. Explain as carefully as you can why.

Explosion in a Steel Box



Imagine that an explosive device was placed in an insulated strong steel box. Then the device is exploded within the insulated box. After the explosion, the temperature and the pressure in the box have increased. The whole system consists of the solid matters from the exploded device, the steel box and the various gases in the box. Which of the following statement is true about internal energy change of the whole system ?

Put a tick in the corresponding box you think the statement is true.

☐ The system has higher internal energy after the explosion.

☐ The internal energy of the whole system is the same before and after the explosion.

☐ The system has higher internal energy before the explosion.

Explain your answer as carefully as possible ....

Two Spontaneous Reaction

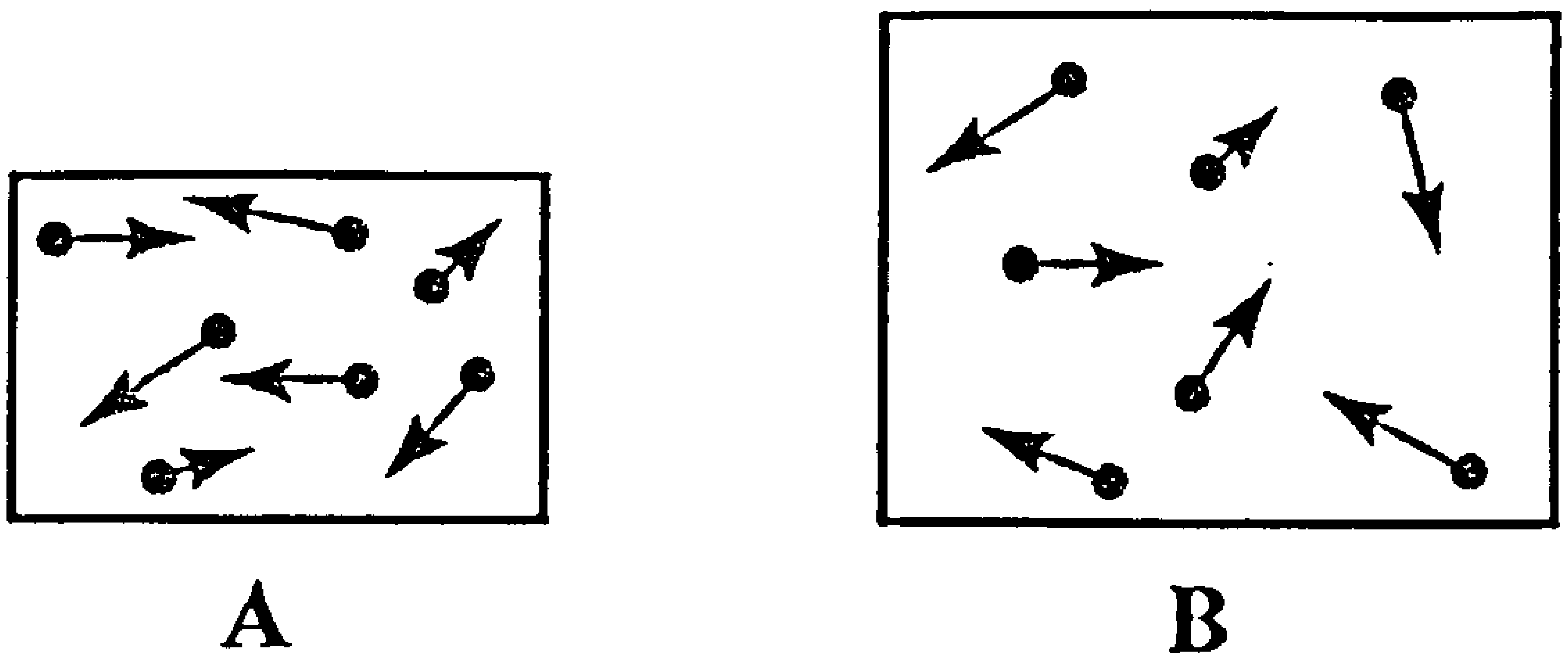
Two spontaneous reaction are given below. Their standard Gibbs free energy changes are also given when the reactions occur.

$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$ $\Delta G^\circ = -2{,}9.\ 10^4$ J/mol

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$ $\Delta G^\circ = -1{,}49.\ 10^6$ J/mol

How would the rate of each reaction compare? Explain your answer as carefully as you can.

Perfect Gases



There is a perfect gas in a vessel (A) at a particular temperature. If the volume of vessel is doubled (B) *isothermally* (means temperature stays the same) , which of the following statements about internal energy of the perfect gas will be true?

Put a tick in the corresponding box you think the statement is true.

☐ The internal energy of the gas will increase.

☐ The internal energy of the gas will not change.

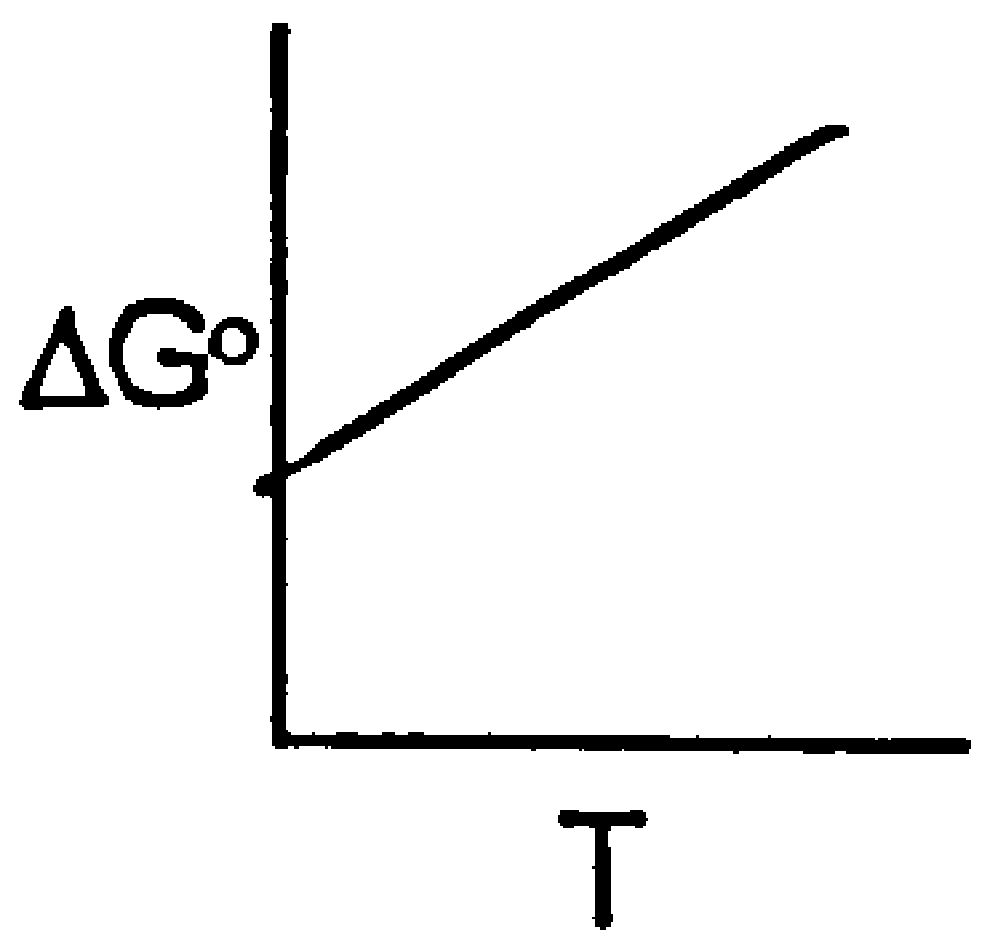
☐ The internal energy of the gas will decrease.

Explain your answer as carefully as you can ....

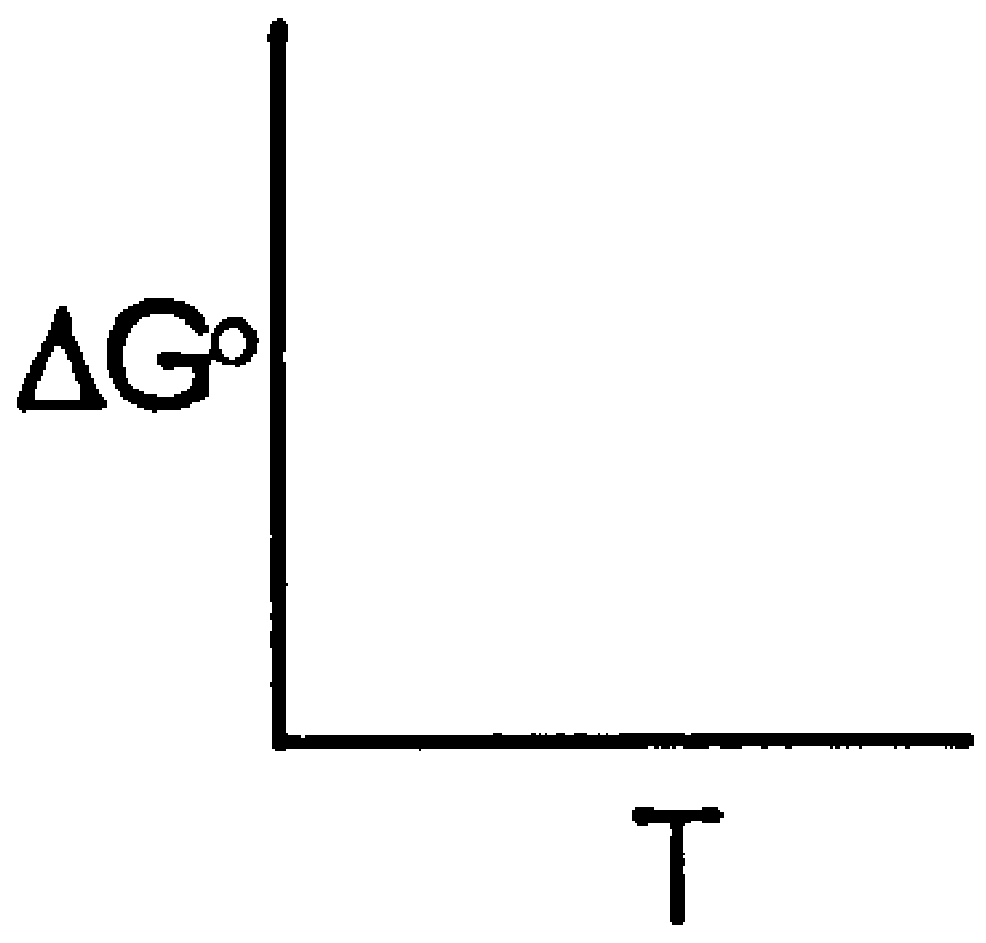
ΔG° and Temperature Change

Which of the following diagrams best represents the change in the reaction standard Gibbs free energy when the temperature increases for the following reaction?

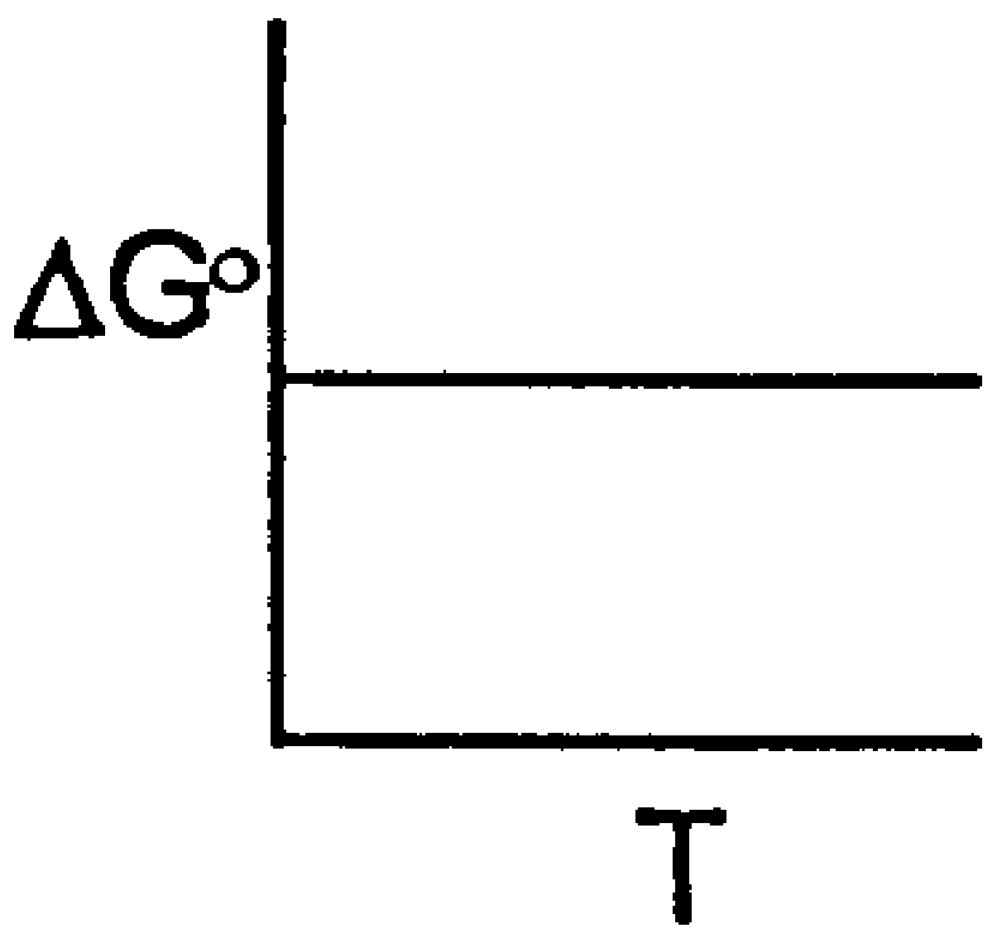
$$2\,H_2(g) \;+\; O_2(g) \;\rightarrow\; 2\,H_2O(g)$$



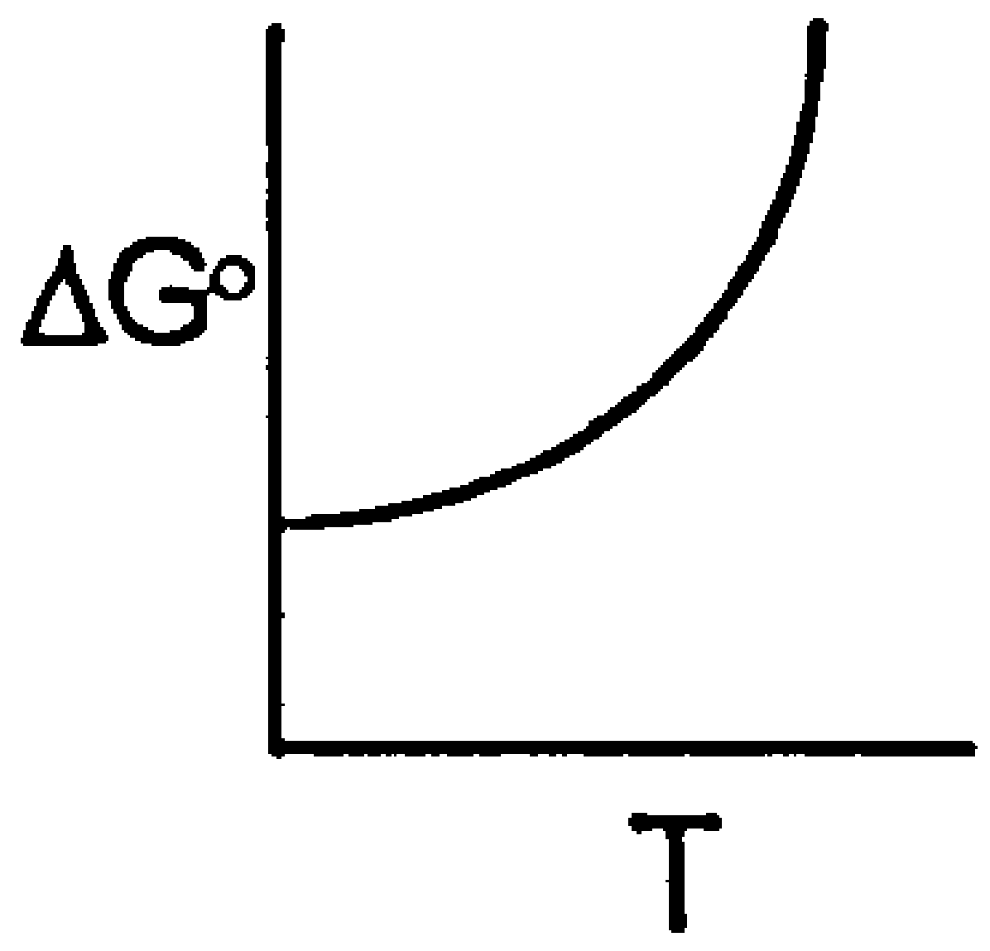
(a)



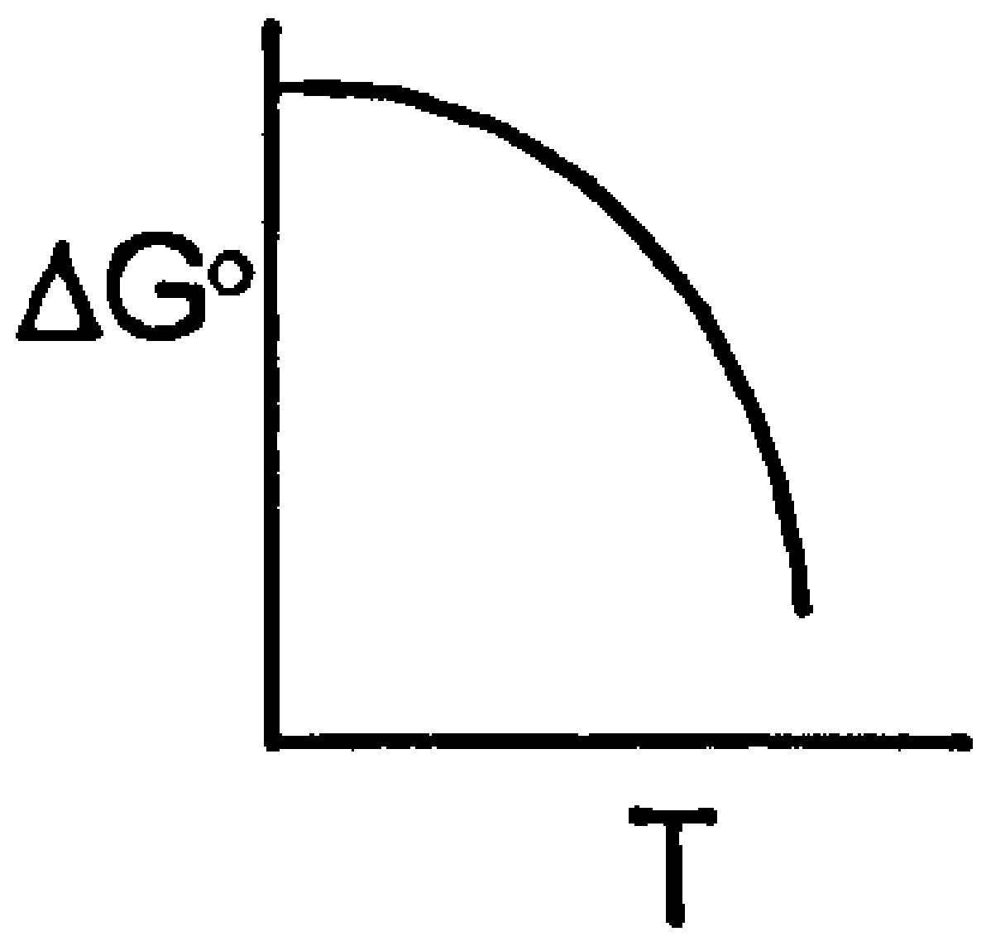
(b)



(c)



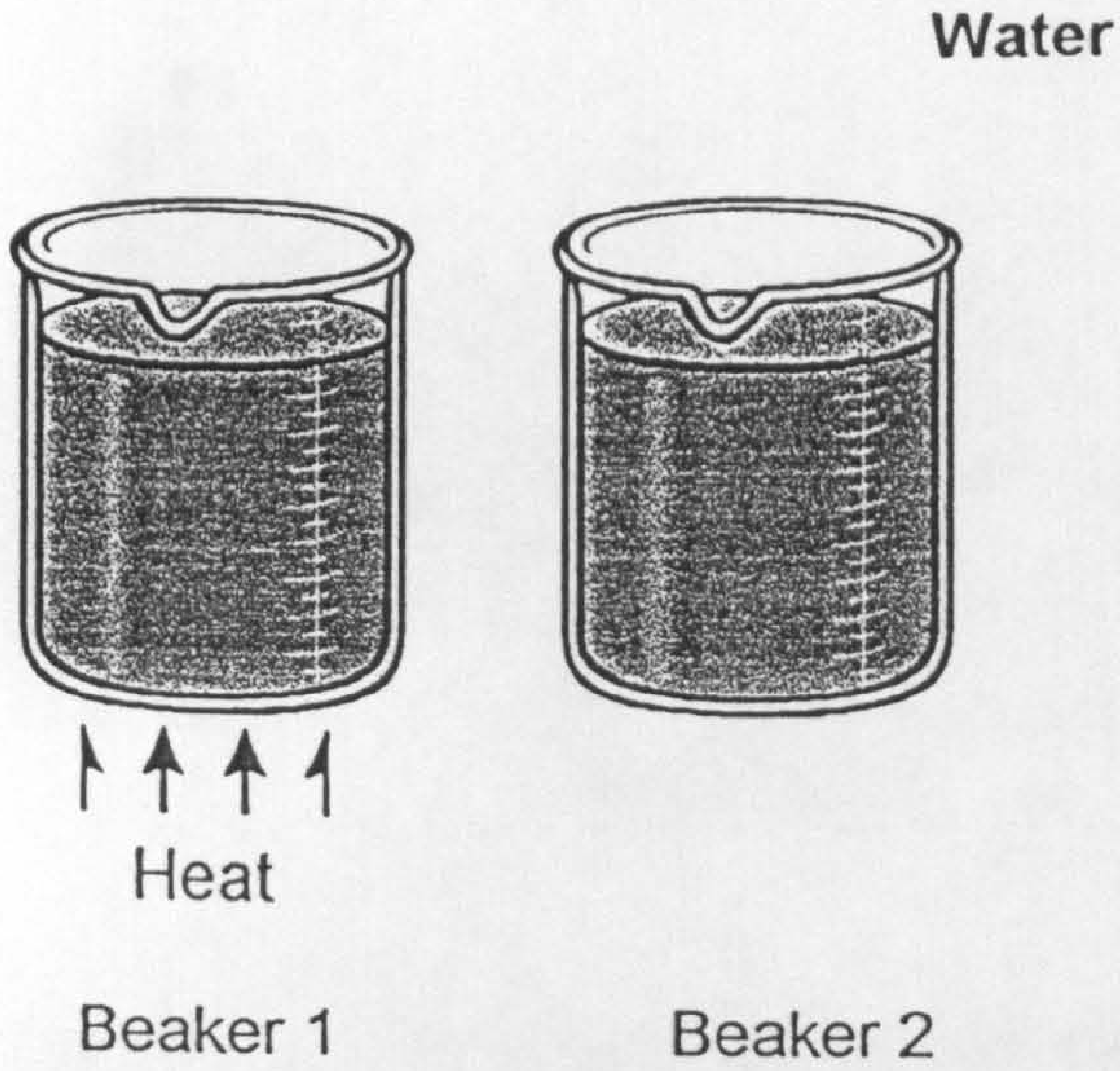
(d)



(e)

Diagram ....best represents the standard Gibbs free energy change when the temperature increases.

Explain your answer as carefully as you can.



Two identical 1 litre glass beakers each contain 900 cm^3 of water. At the starts, both beakers are at room temperature (25 ^{o}C). Later, Beaker 1 is heated by a candle for five minutes while Beaker 2 is stirred vigorously at room temperature for five minutes.

Which of the following statements are true about the final internal energies of the two beakers and their contents relative to their initial internal energies?

Put a tick in the corresponding box you think the statement is true.

☐ The final internal energy in each case is more than the initial internal energy.

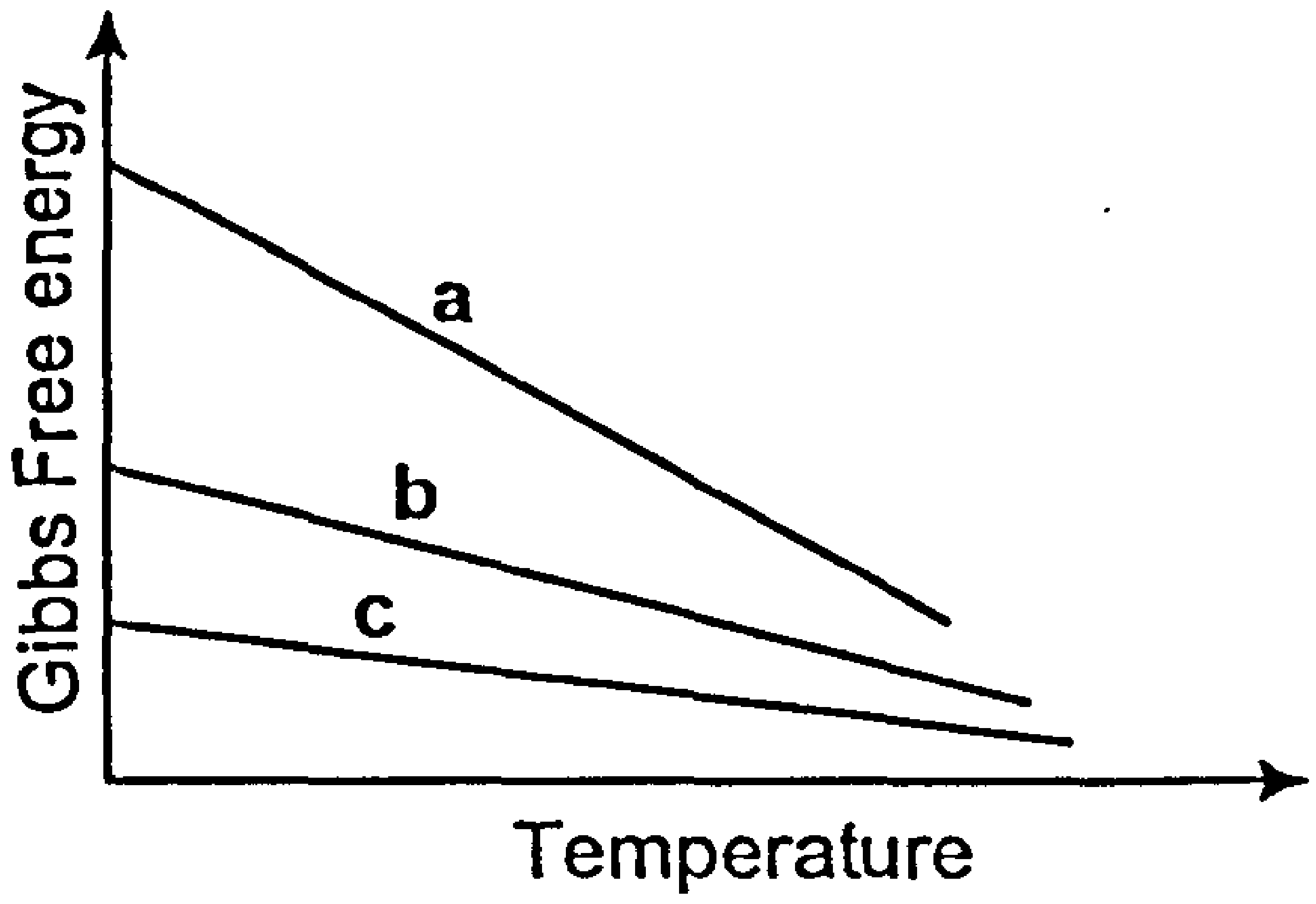
☐ The final internal energy of Beaker 1 and contents has increased, while the final internal energy of Beaker 2 and contents has remained the same.

☐ The final internal energy of Beaker 1and contents has remained the same, while the final internal energy of Beaker 2 and contents has increased.

☐ There is no change in the internal energy of either Beaker 1 and contents or Beaker 2 and contents relative to the initial internal energy.

Explain your answer as carefully as possible ....

Gibbs Free Energy Change with Temperature



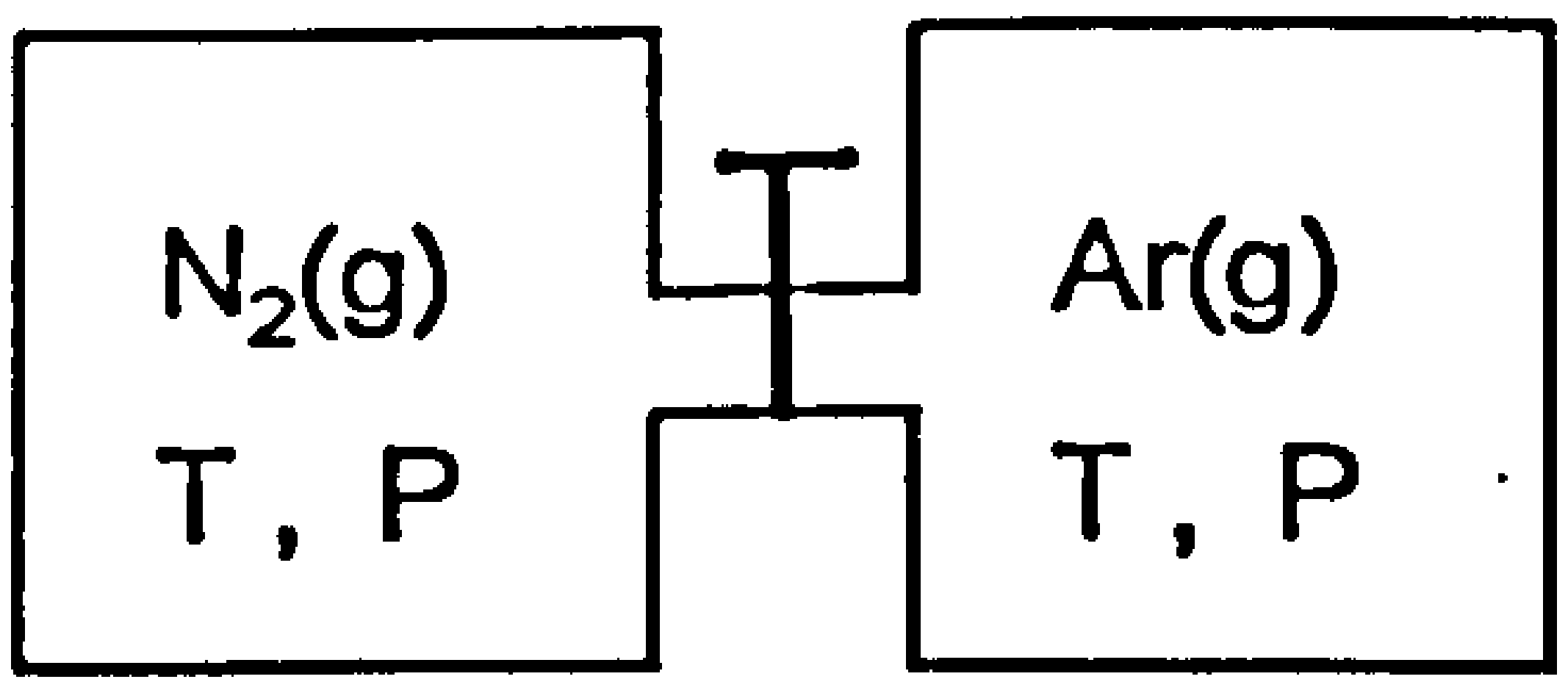
The variation of the Gibbs free energy with the temperature is determined by the entropy at constant pressure. The graph shows the change in Gibbs free energy when the temperature increase for gas, liquid and solid states of the same substance at constant pressure.

Decide which line on the graph shows the Gibbs free energy changes with increasing temperature for the gas state of the substance and explain how you decided.

Line............... on the graph shows the Gibbs free energy change when the temperature increase at constant pressure.

Explanation

Mixing of the Gases



Imagine that two gases, nitrogen and argon, placed in equal volume containers which are connected with each other by a tap. Their initial pressures are P. At constant temperature the tap is opened and two gases are allowed to mix. After the mixing, the entropy of gases increases and their final total pressure is P. Using these information:

a) Explain as carefully as you can why the entropy increases.

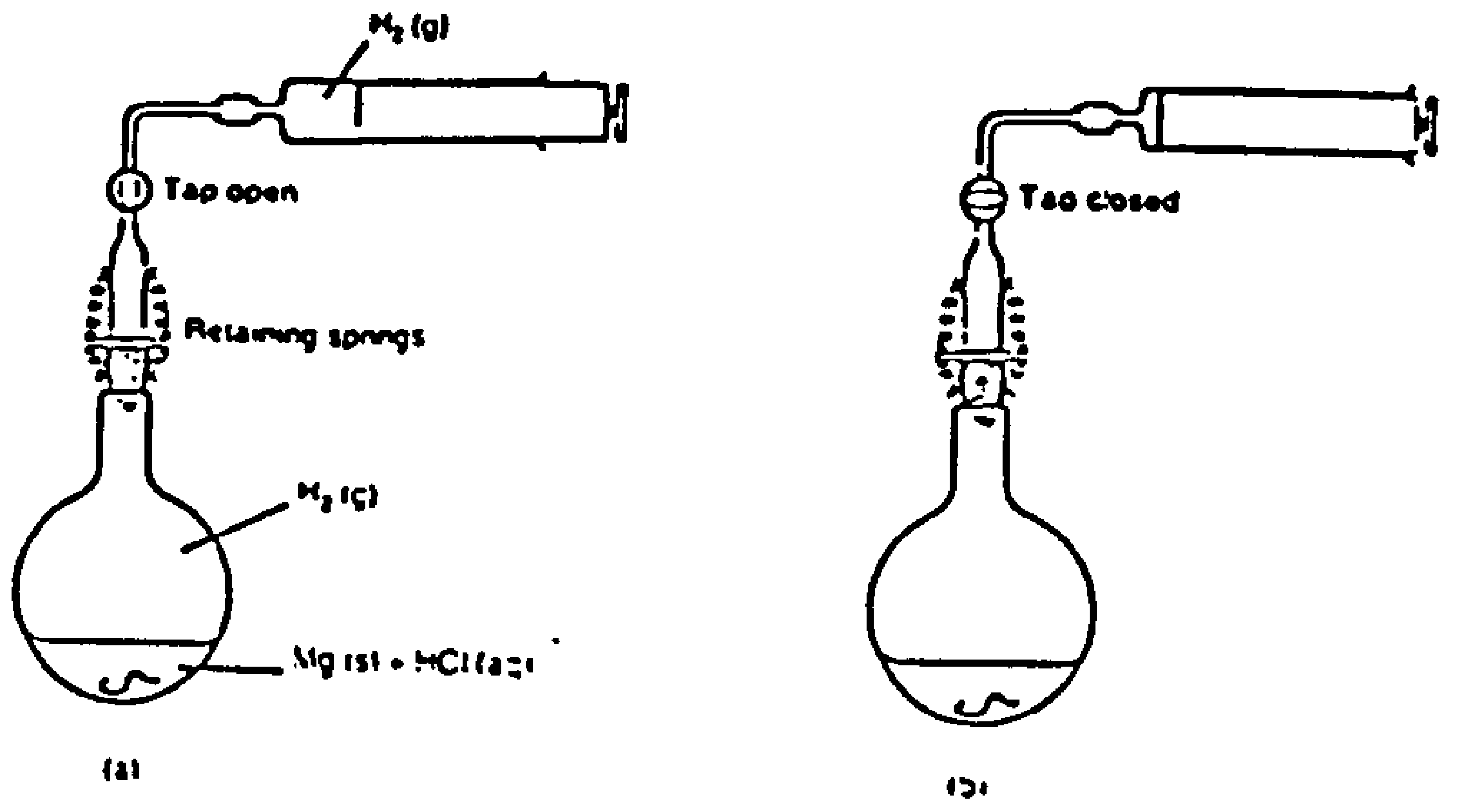
b) Estimate how the enthalpy of the gases changes, and explain your answer as carefully as you can.

c) Estimate how the Gibbs free energy of the gases changes, and explain your answer as carefully as you can.

Magnesium

Consider the same reaction

$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta H = -463\ kJ\ mol^{-1}$$



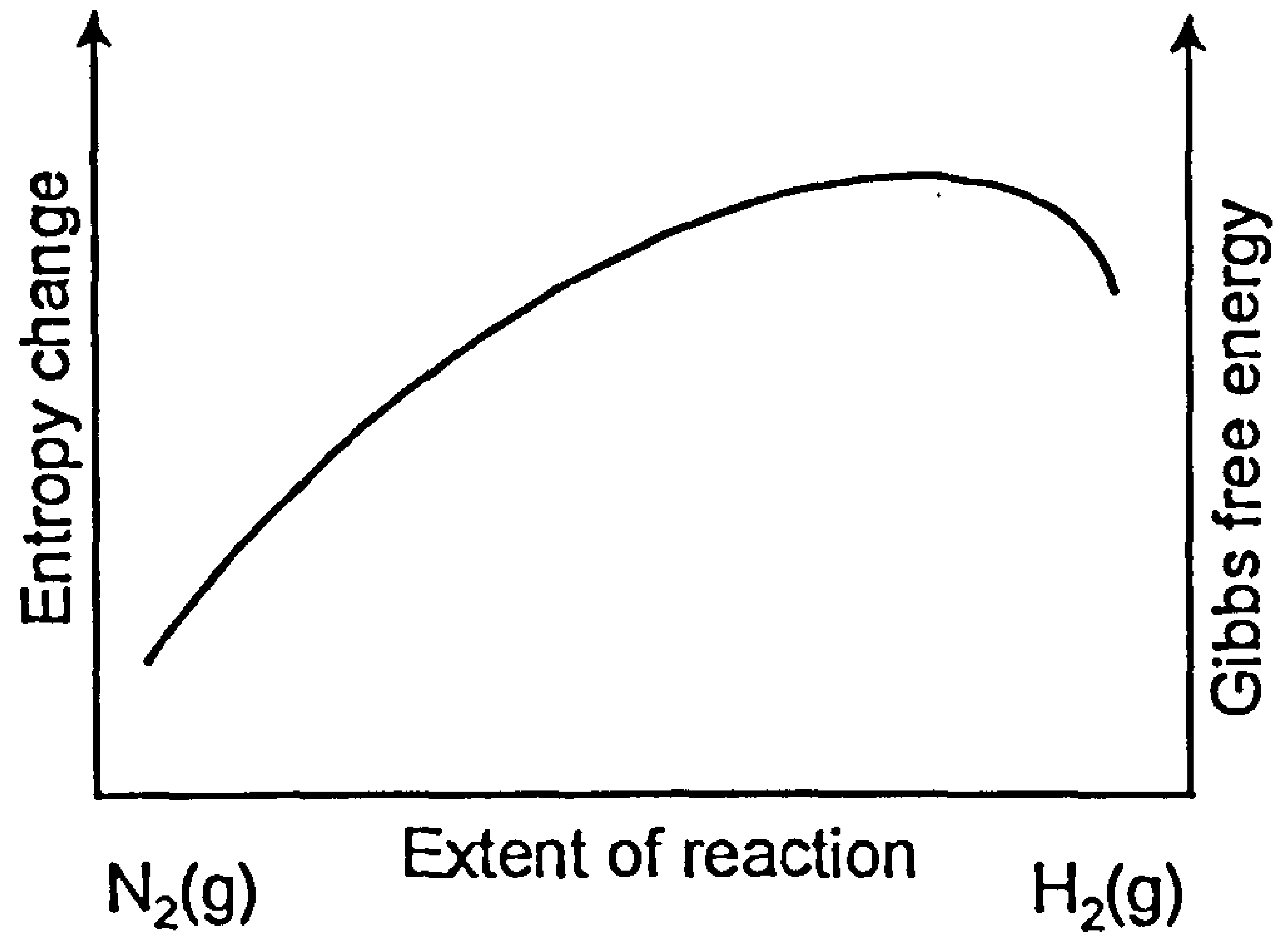
taking place in each set of apparatus shown here. In a the tap is open; in b tap is closed, and equal amounts of reactants are used in each case.

Consider that the reactions are completed and the systems are cooled down to the beginning temperature. Suppose that it is possible to measure the heat given out to the surroundings.

a) In which set of apparatus do you think most heat given out to the surroundings? Explain your answer as carefully as you can.

b) Decide that in which set of apparatus heat change equals to the reaction enthalpy change and internal energy change. Explain your answer as carefully as you can.

Entropy Change



The graph shows the total entropy changes during the Haber process reaction;

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$$

On the same graph draw the Gibbs free energy changes during the process and explain your answer as carefully as you can.

Hypothetical Reactions

The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1	$A + B \rightarrow C + D$	Exothermic
Reaction 2	$E + F \rightarrow G + H$	Endothermic

Tick the box you think statement is true about the rate of the reactions, and explain how you decided which box to tick.

☐ Reaction 1 occurs rapidly.

☐ Reaction 2 occurs slowly.

☐ Reaction 1 is always faster than reaction 2.

☐ Reaction 2 may be faster than reaction 1.

☐ Both reaction 1 and reaction 2 occurs slowly.

Explanation

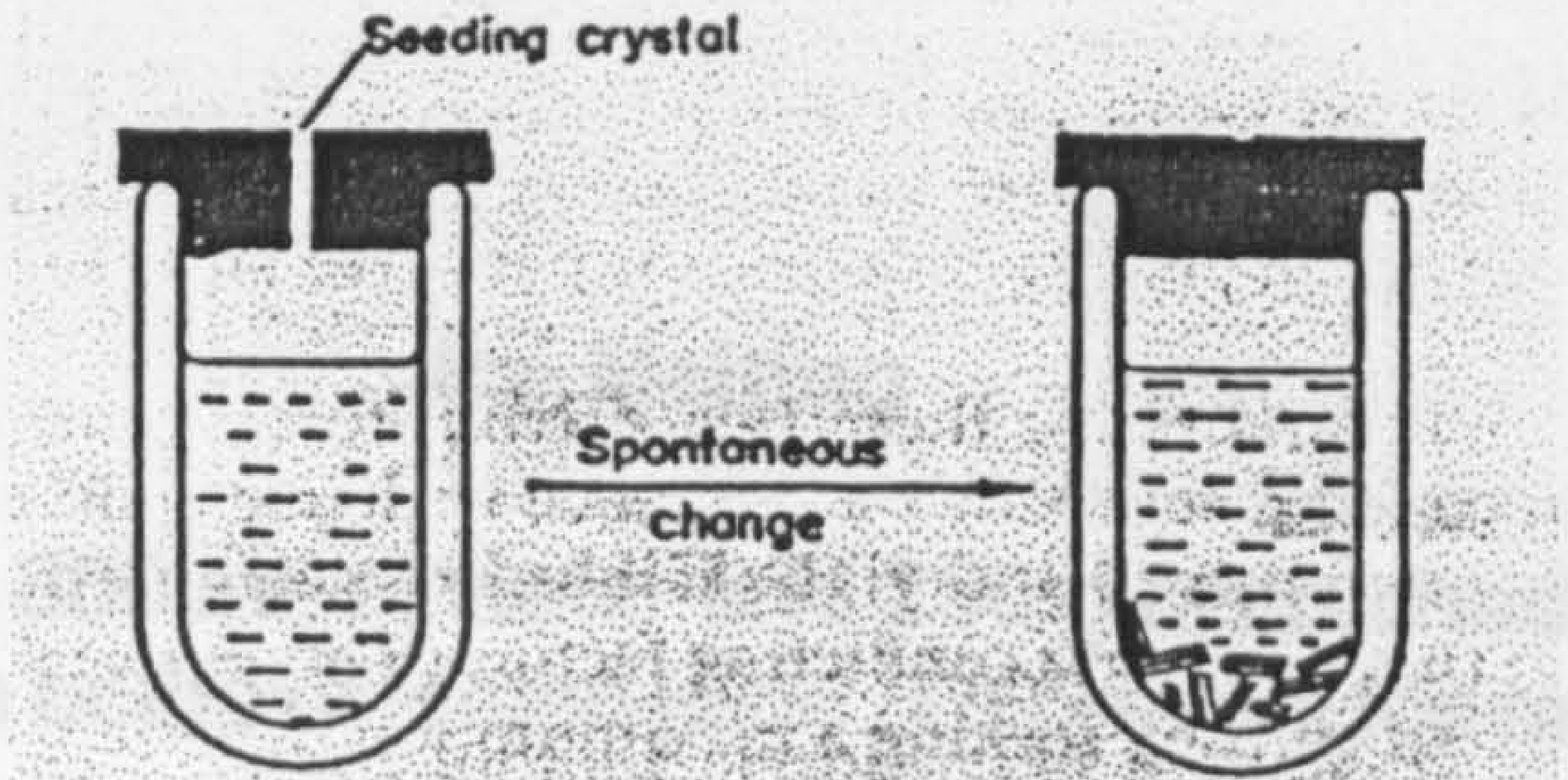
Extent of Reaction

The following table shows the Gibbs free energy change with the extent of reaction during an equilibrium reaction at constant temperature.

extent of reaction	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
ΔG (J/mol)	- 3098	- 5160	- 6744	- 7952	- 8810	- 9311	- 9412	- 9017	- 7899

Decide where the reaction reaches equilibrium and explain how you decided.

Spontaneous Change



A saturated hot solution of sodium thiosulphate is allowed to cool slowly. If care has been taken to keep the materials clean and dust free , supercooling by several degrees is possible. The solution is then sealed in a Dewar flask which does not allow to energy transfer between system and surrounding. On dropping a tiny seeding crystal through a hole in the lid (see figure) crystallization occurs, with an apparent increase of organisation.
According to this explanation, which of the following statements are true about entropy change of the system when the crystals form?

Put a tick in the corresponding box for each of the true statements.

☐ There is no entropy change in the system.

☐ Entropy of the system increases.

☐ Entropy of the system decreases.

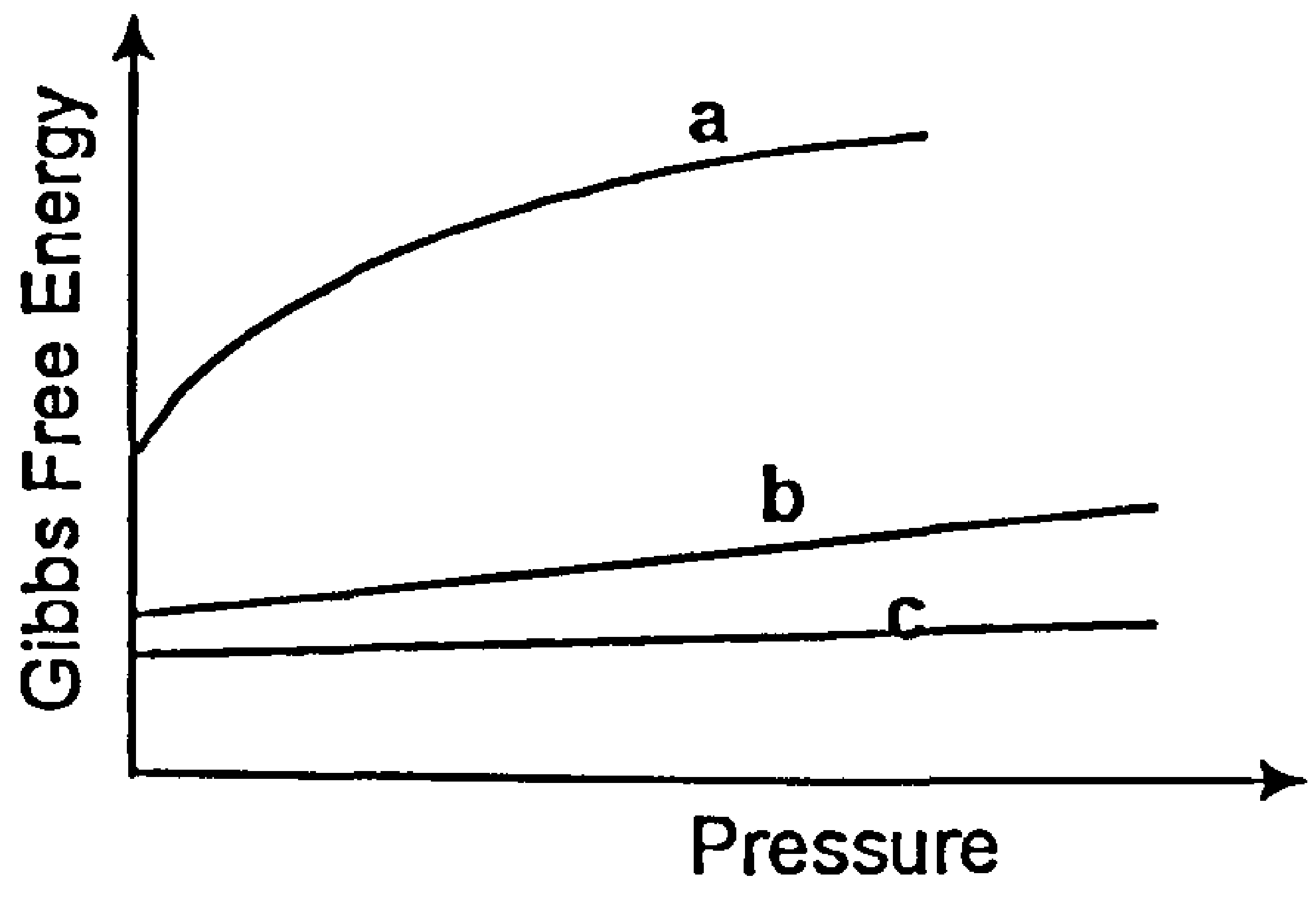
Explain your answer as carefully as possible..............

Ice Melting

Consider that you put 300 mL of water and 250 g of crushed ice in two identical 1 L of glass beaker to keep cold a bottle of lemon juice. To prevent ice melting you advised to add some salt into the water. You have the same mole amount of NaCl and KI salt and it is known that enthalpy change of those two salts when they dissolve in water are 4 kJ mol^{-1} and 22 kJ mol^{-1} respectively.

Which salt do you prefer to keep the ice in water for a long time? Explain your answer as carefully as you can.

Gibbs Free Energy Change with Pressure



The variation of the Gibbs free energy with the pressure is determined by the volume of the sample at constant temperature. The graph shows the change in Gibbs free energy with the increasing pressure at constant temperature for the gas, liquid and solid states of the same substance.

Decide which line belongs to which phase of the substance and explain how you decided.

The line.............represents the Gibbs free energy change with increasing pressure for the gas phase of the substance.

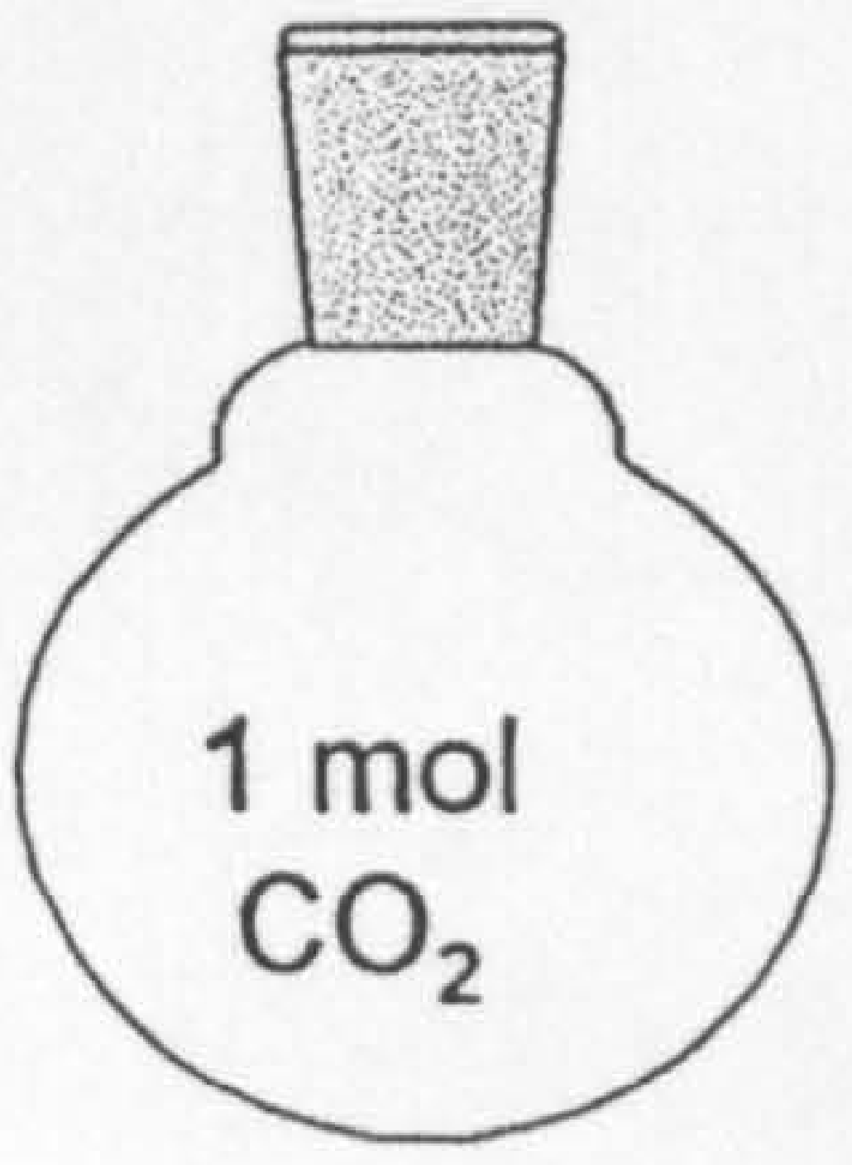
The line.............represents the Gibbs free energy change with increasing pressure for the liquid phase of the substance.

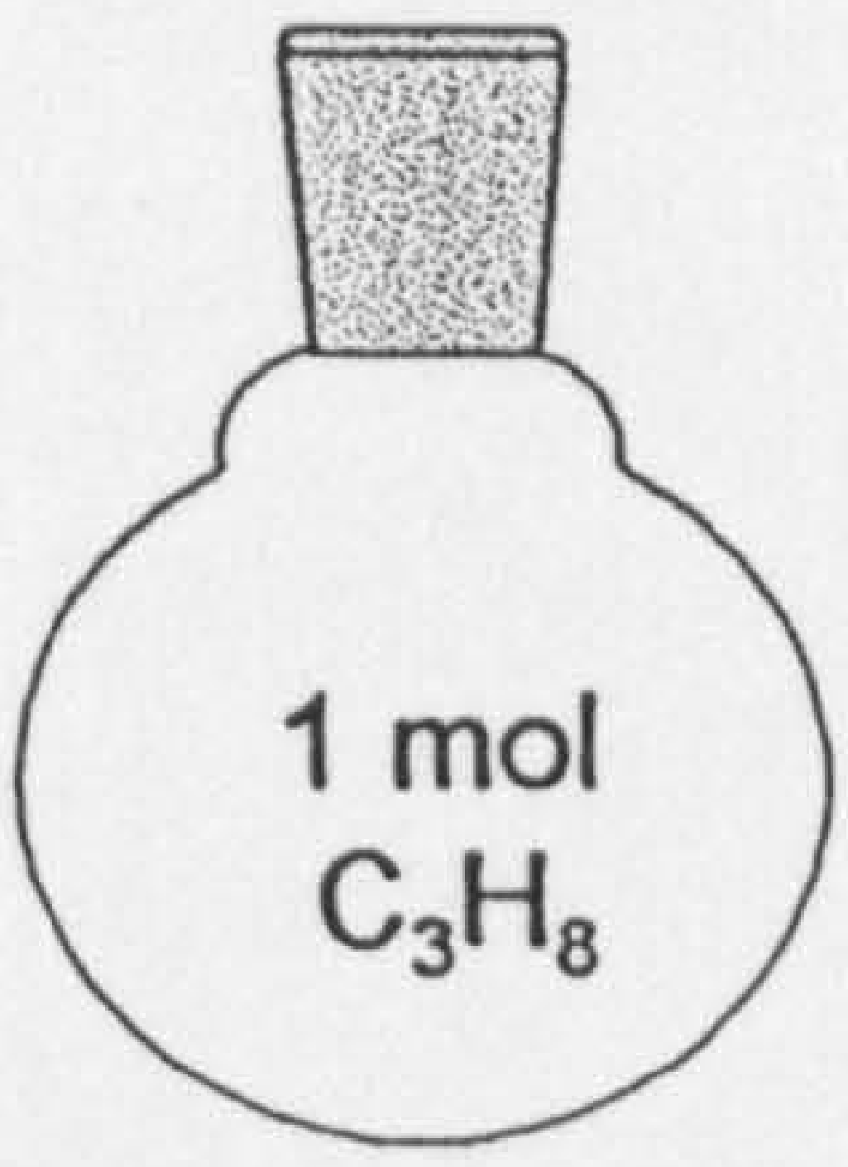
The line.............represents the Gibbs free energy change with increasing pressure for the solid phase of the substance.

Explanation

Carbon Dioxide and Propane

Carbon dioxide and propane gases have the same molar mass. There are two identical glass balloon one of those is fulled with 1 mole of carbon dioxide gas and the other is fulled with 1 mole of propane gas are shown below.





Which gas do you think has the greater entropy value ? Explain your answer as carefully as you can.

Appendix 2

The Pilot Study Questionnaire-2

Name:________________

Date:__________________

Start Time:____________

Finish Time:____________

AN INVESTIGATION *of* UNIVERSITY STUDENTS' IDEAS ABOUT INTERNAL ENERGY, ENTHALPY, ENTROPY AND GIBBS FREE ENERGY

Time Required : Approximately 100 minutes

Before you start please read the letter on the next page.

Mustafa SOZBILIR

Department of Educational Studies
University of York
York YO10 5DD

Dear Student,

You may be wondering why you are being asked to complete this test!

I am a researcher working on a research project to find out university chemistry students' ideas about some aspects of chemistry. The study is taking place over three years. Similar tests will be given to the students who follow you to on the course. Your responses to the questions will help tutors and lecturers gain a better understanding of the ideas of the thermochemistry students find difficult.

The test is designed to reveal what chemistry students really understand. You are encouraged to put your own ideas. I am asking you to answer honestly. If you are not able to answer the question, don't panic! This is not an exam. You don't need to force yourself to give an answer. Don't look for tricks (none are intended) and lengthy answers are not expected.

The test may seem to be a lot of pages, but the print is big and there are lots of pictures and plenty of space. So, don't worry about the quantity of the pages!

If you are not able to give an answer to a questions pass on to the next one. Don't spend too long time for any one. 5 minutes should be enough for each question.

I would not be able to give an answer to any question asked in the test. If you enquire more about the answer, you may do a search for yourself or discuss with your lecturer. This is because of the confidentiality of the research study. I apologise for any inconvenience about this issue.

It would be great help to me if you could write the time you started and completed the test on the front cover. All the responses from you and information about you will be confidential and will only be used for the research study.

I am planing to interview a small group of students to gather more information on possible areas of difficulty. These interviews will be recorded for research purposes only. If you do not want to be interviewed, please tick the box here ☐.

Thank you very much for completing the test.

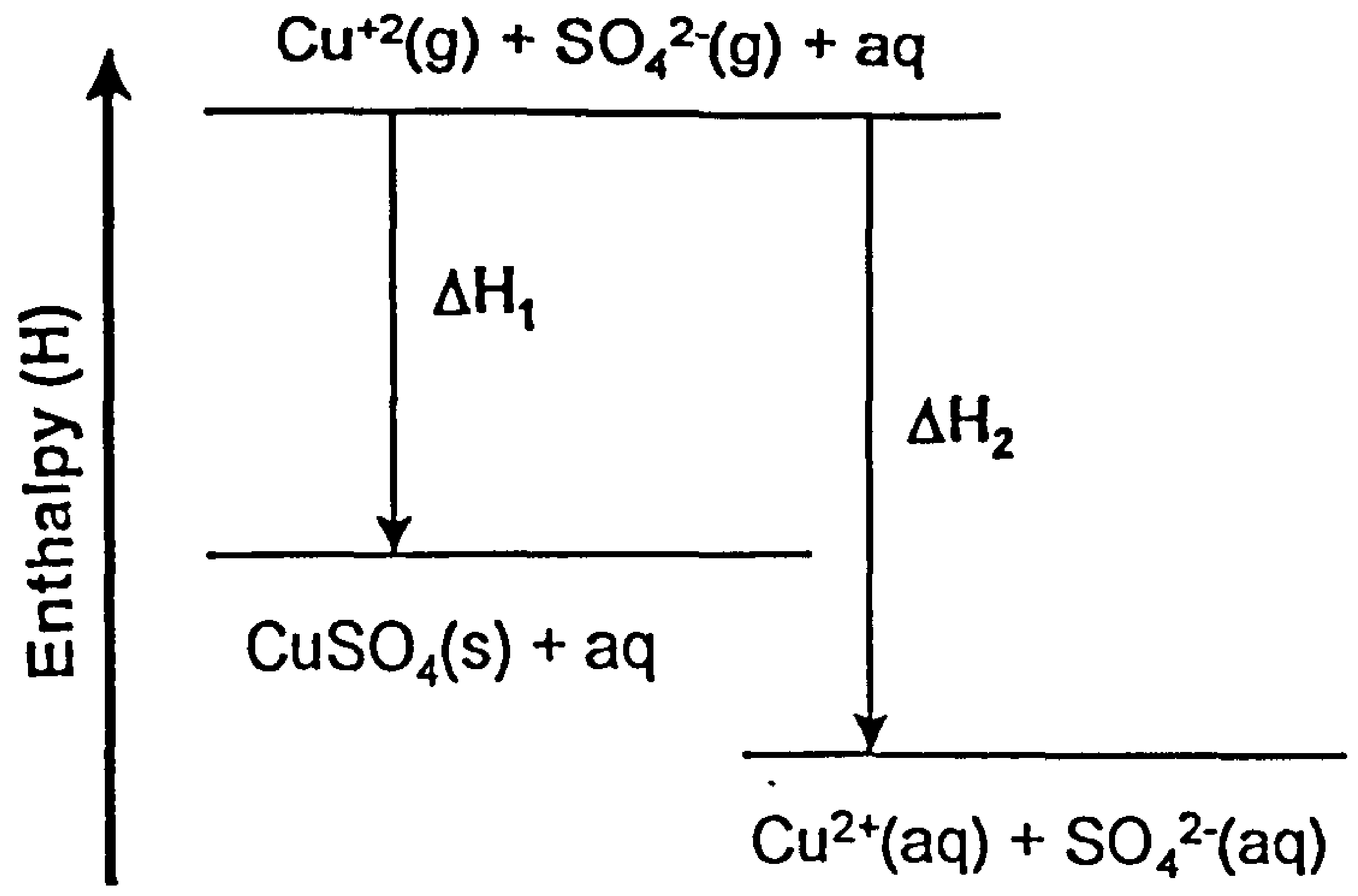
May 1998

Yours sincerely

M. SÖZBİLİR

Copper (II) Sulphate

An energy-level diagram is shown below for the dissolving of anhydrous copper (II) sulphate.



a) Draw an arrow on the diagram above to represent the enthalpy change of solution (ΔH_{soln}) of $CuSO_4(s)$, and decide that what is the name of the enthalpy changes indicated by ΔH_1 and ΔH_2 in the diagram.

b) Explain, as carefully as you can, what the energy level diagram is telling you.

Helium and Carbon Dioxide

a)

Contains He
n = 1 mol
V = 1 L
T = 298 K

Contains CO_2
n = 1 mol
V = 1 L
T = 298 K

The two containers contain one mole of helium and carbon dioxide at the same temperature.

How does the average kinetic energy of the helium gas compare with that of the carbon dioxide? Explain your answer as carefully as you can.

b)

A
Contains He
n = 1 mol
V = 1 L
T = 298 K

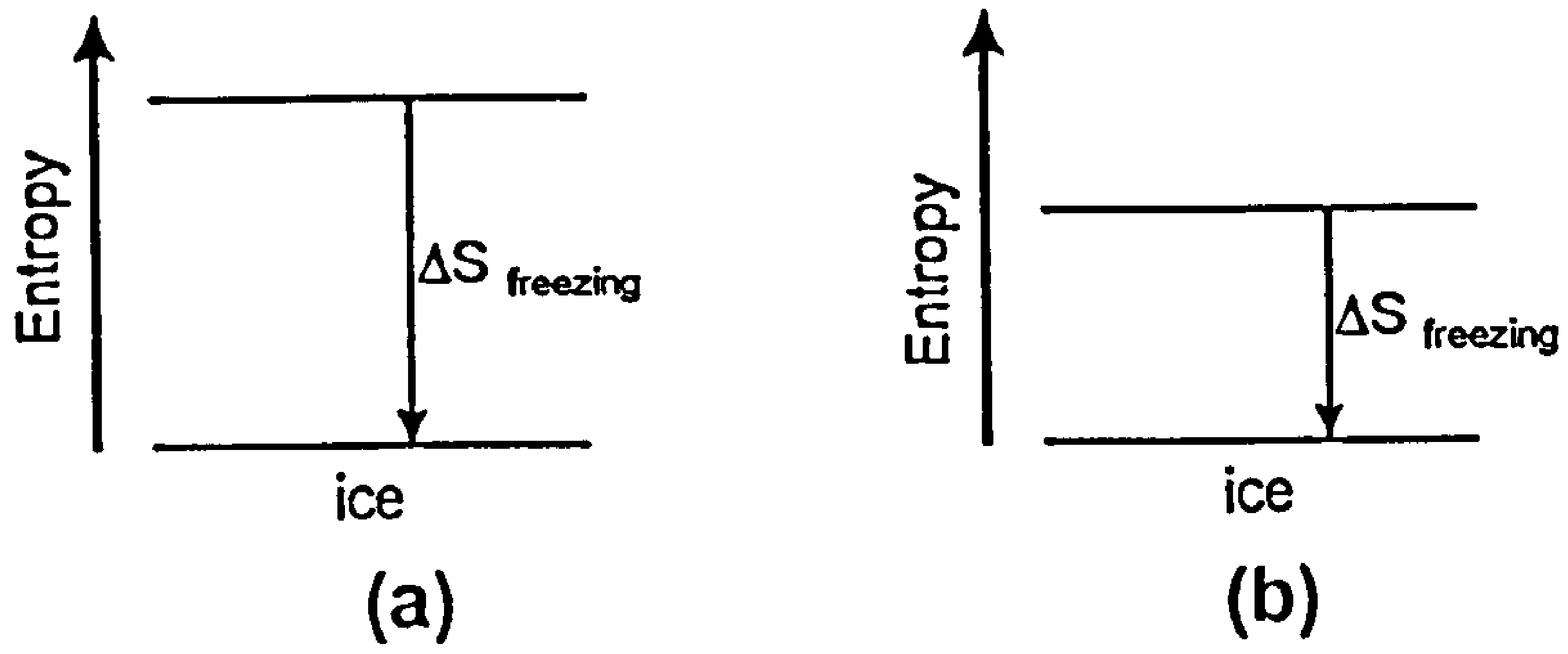
B
Contains He
n = 1 mol
V = 0,5 L
T = 298 K

The two containers contain one mole of helium at the same temperature.

What do you think about average kinetic energy of the gases. Explain as carefully as you can.

Seawater

Seawater contains different kinds of dissolved minerals, therefore freezes at a lower temperature than pure water. The released energy is the same when seawater and pure water freeze. Two diagrams below show the entropy change of the freezing seawater and the pure water.



a) Decide that which diagram represents the entropy change of the seawater when it freezes, and explain your answer as carefully as you can.

b) The entropy change of the freezing of pure water is:

$H_2O(l) \rightarrow H_2O(s) \qquad \Delta S = -22{,}0\ kJ\ mol^{-1}$

What do you think about the entropy of the surroundings before the freezing can occur. Explain your answer as carefully as you can.

Energy

a) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H^\ominus = -286 \text{ kJ mol}^{-1}$

This thermochemical equation tell us that 286 kJ of energy are released when one mole of hydrogen molecules reacts with oxygen molecules to form one mole of water molecules.

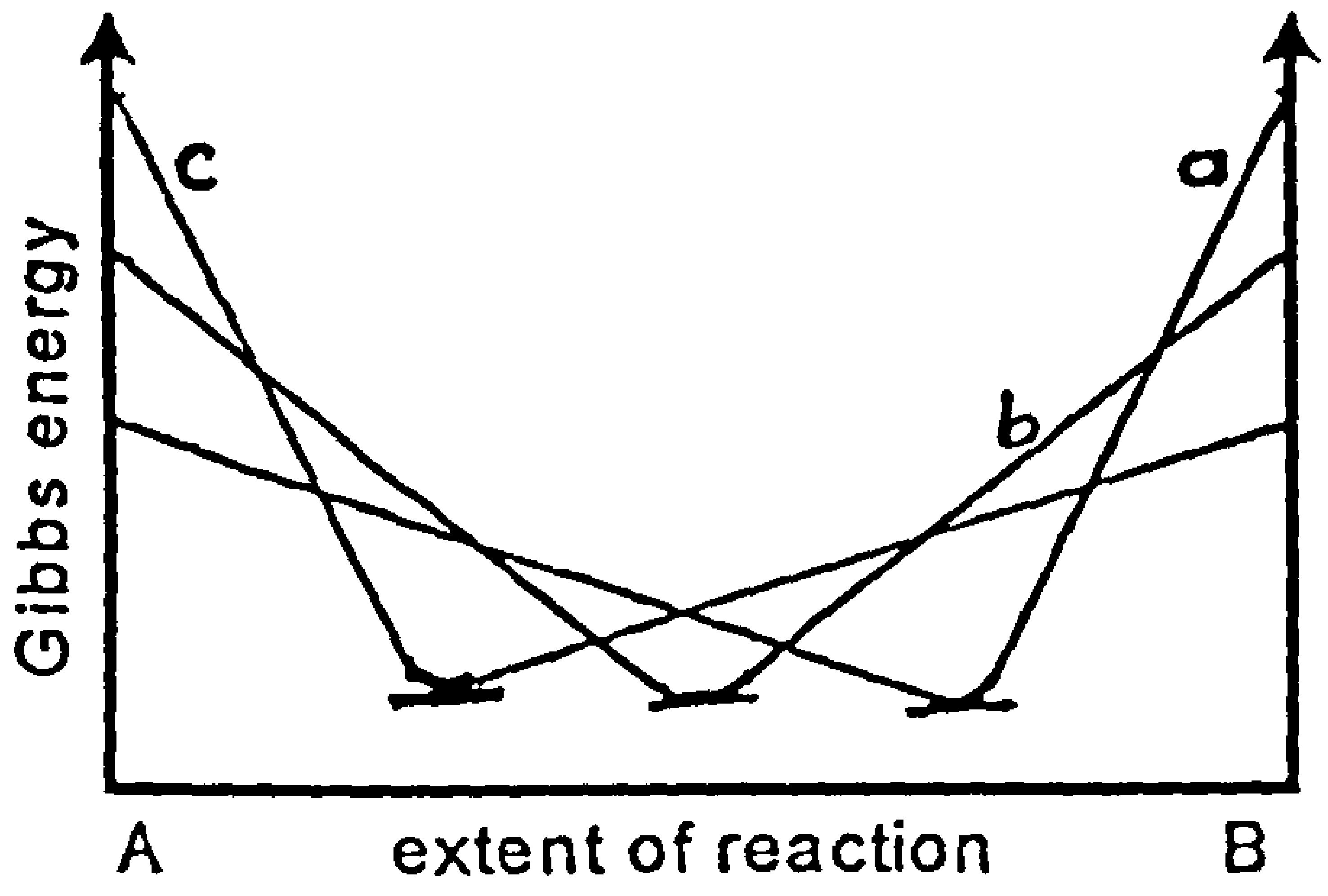
Explain as carefully as you can why energy is released in this reaction.

b) $N_2(g) + 2 O_2(g) \rightarrow 2 NO_2(g)$ $\Delta H^\ominus = 68 \text{ kJ mol}^{-1}$

This thermochemical equations tells us that 68 kJ of energy are required when one mole of nitrogen molecules react with oxygen molecules to form two moles of nitrogen dioxide molecules.

Explain as carefully as you can why energy is absorbed in this reaction.

Gibbs Free Energy



The figure shows Gibbs free energy changes against extent of reaction for the reaction A $\leftrightharpoons$ B with different initial proportions of A and B. According to this figure which of the following statement are true ?

Tick the box you think true and explain how you decided which box to tick.

☐ Graph **'a'** shows that equilibrium lies close to pure A.

☐ Graph **'b'** shows that equilibrium corresponds to A and B present in similar proportion.

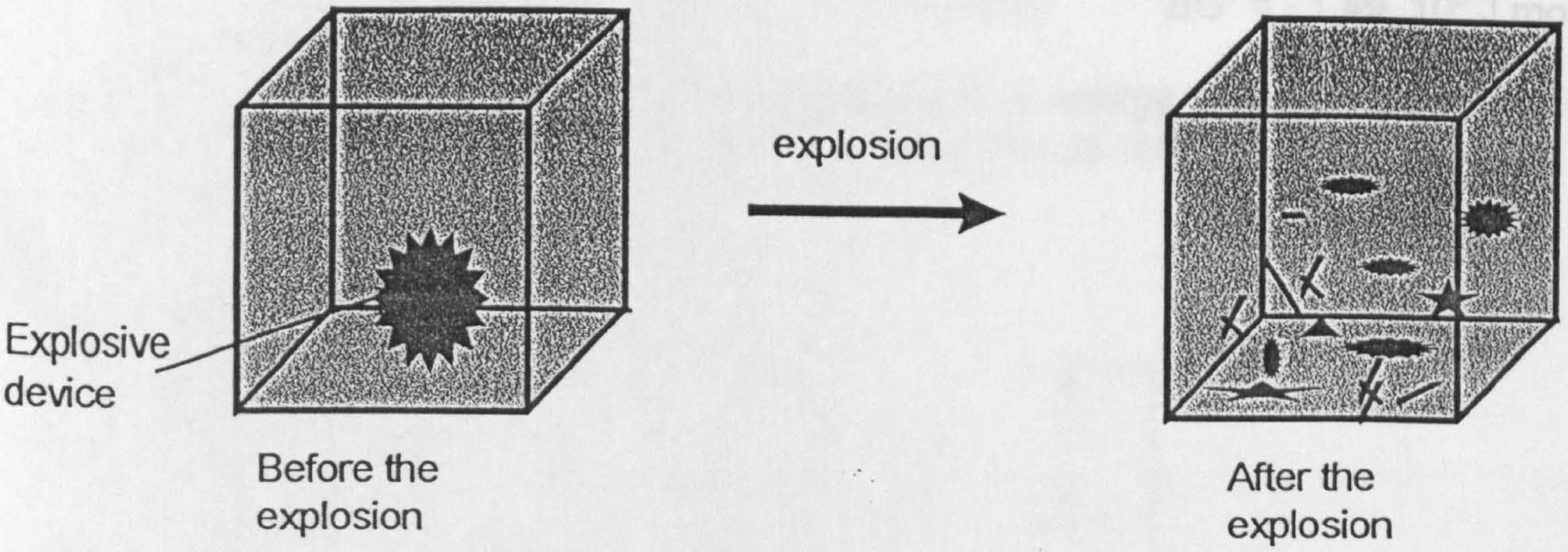
☐ Graph **'c'** shows that equilibrium lies close to pure B.

Explanation

Potential Energy

The potential energy of the perfect gas molecules assumed as zero. Explain as carefully as you can why.

Explosion in a Steel Box



Imagine that an explosive device was placed in an insulated strong steel box. Then the device is exploded within the insulated box. After the explosion, the temperature and the pressure in the box have increased. The whole system consists of the solid matters from the exploded device, the steel box and the various gases in the box.

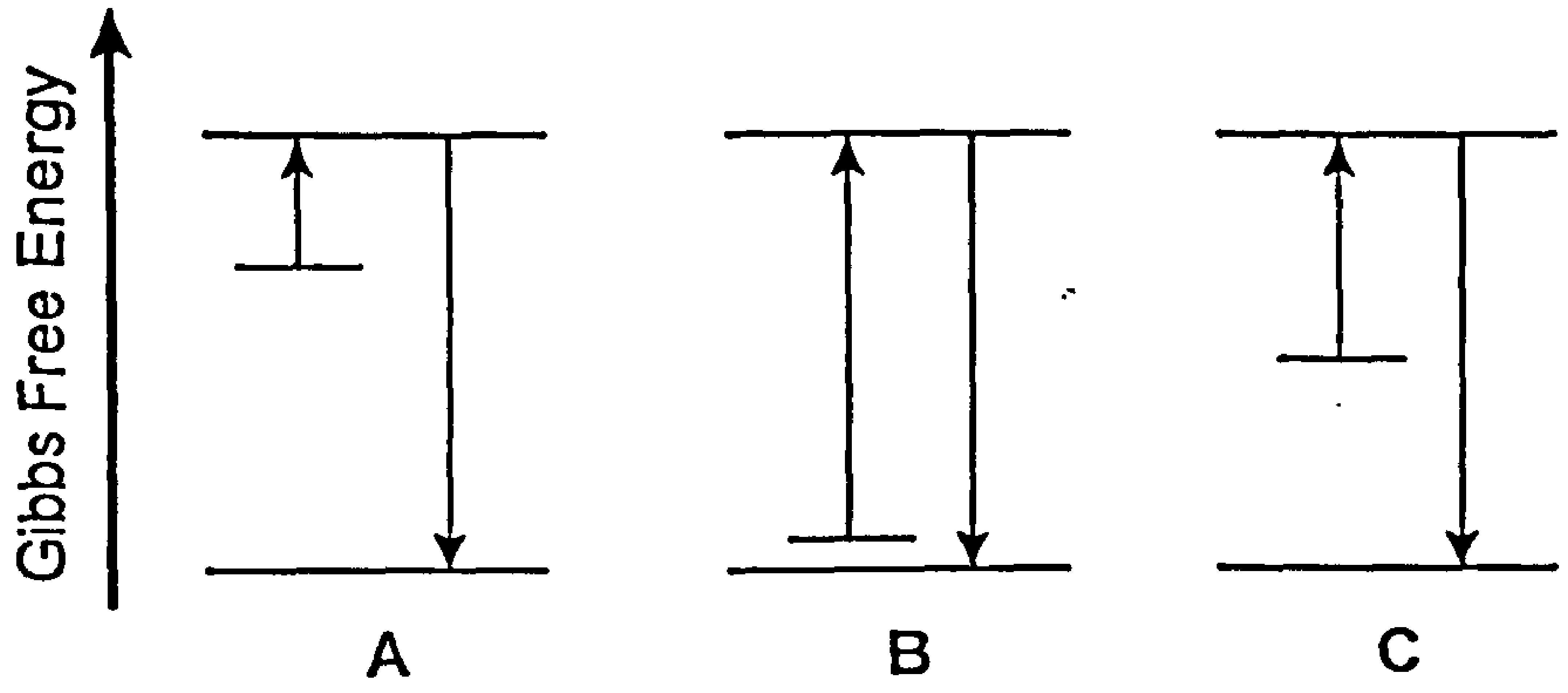
What do you think will happen to the internal energy of the system after the explosion? Explain your answer as carefully as you can.

Rusting of Iron

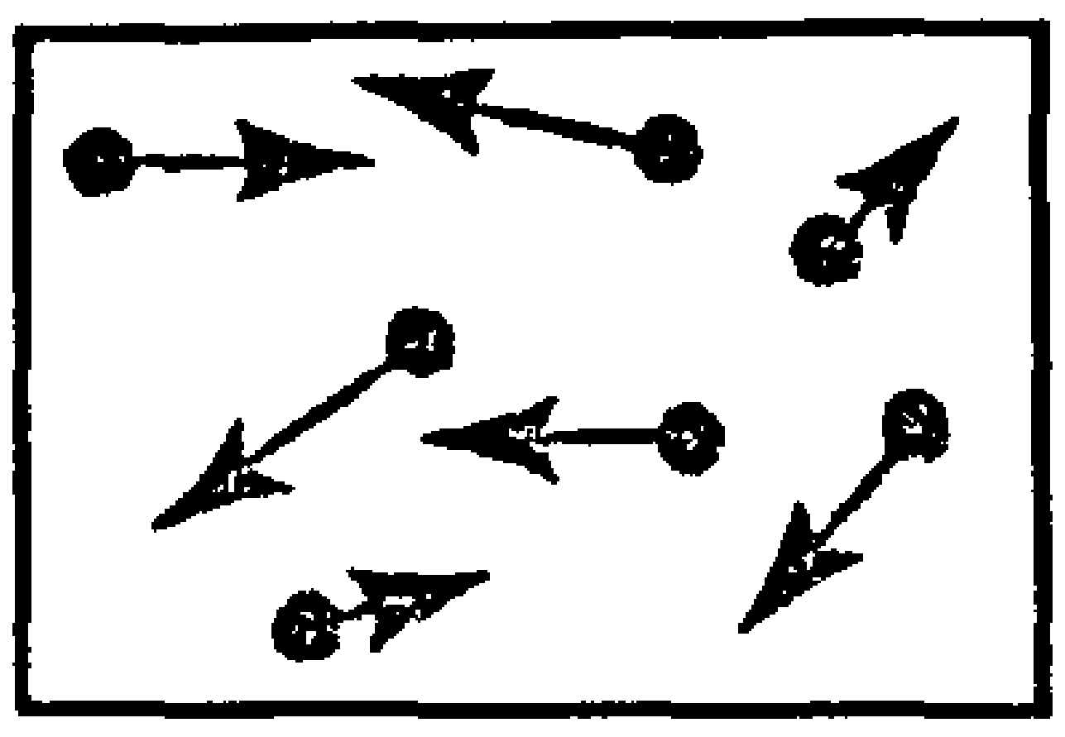
The rusting of iron is a very slow process. The chemical reaction for the rusting process can be given like this:

$$4\,Fe(s) + 3\,O_2(g) \rightarrow 2\,Fe_2O_3(s) \qquad \Delta G^\circ = -1{,}49.\ 10^6\ J\ mol^{-1}$$

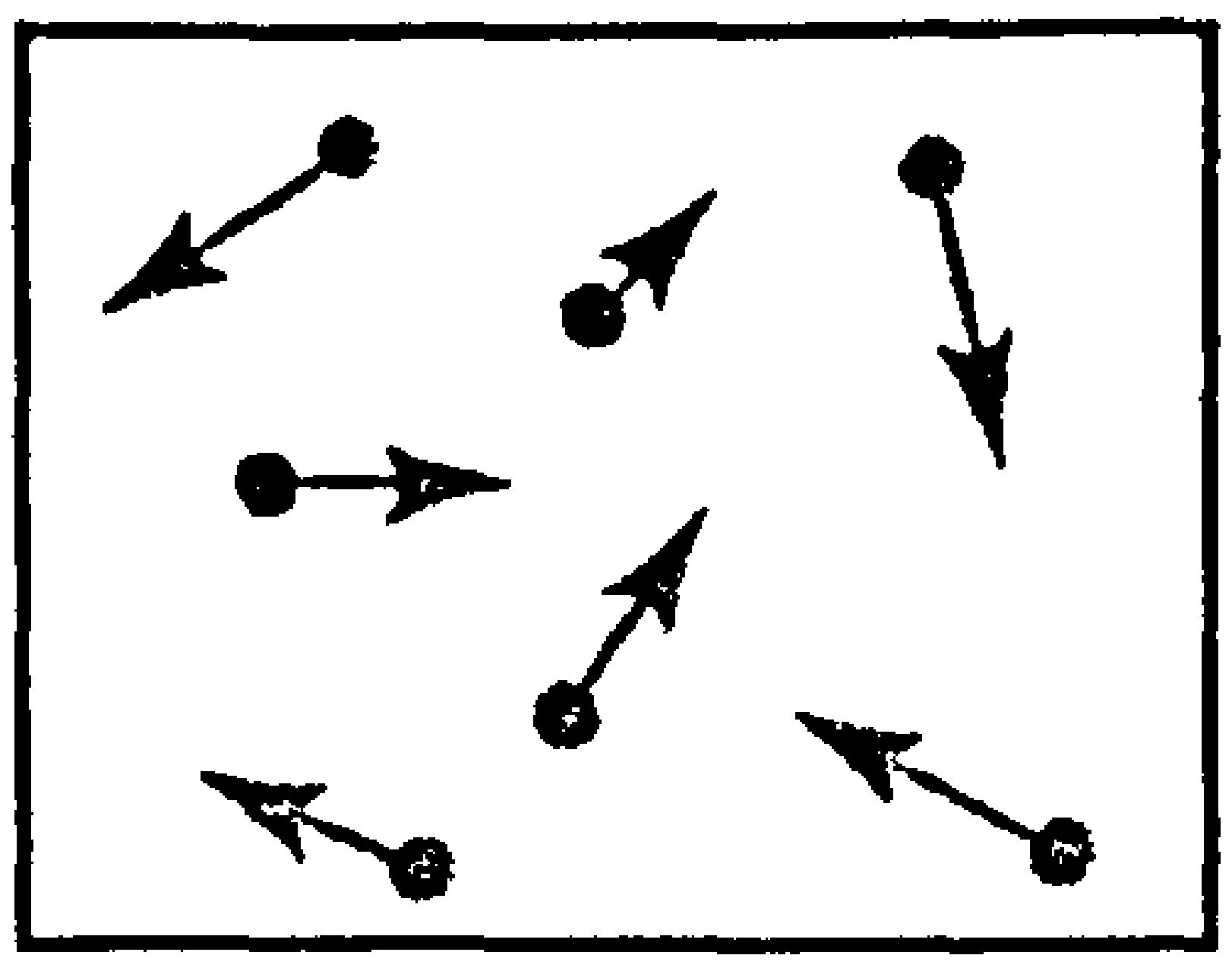
The three diagrams below represent the Gibbs free energy changes. Which of these diagrams do you think best represents Gibbs free energy change of the rusting of iron? Explain your answer as carefully as you can.



Perfect Gases



A



B

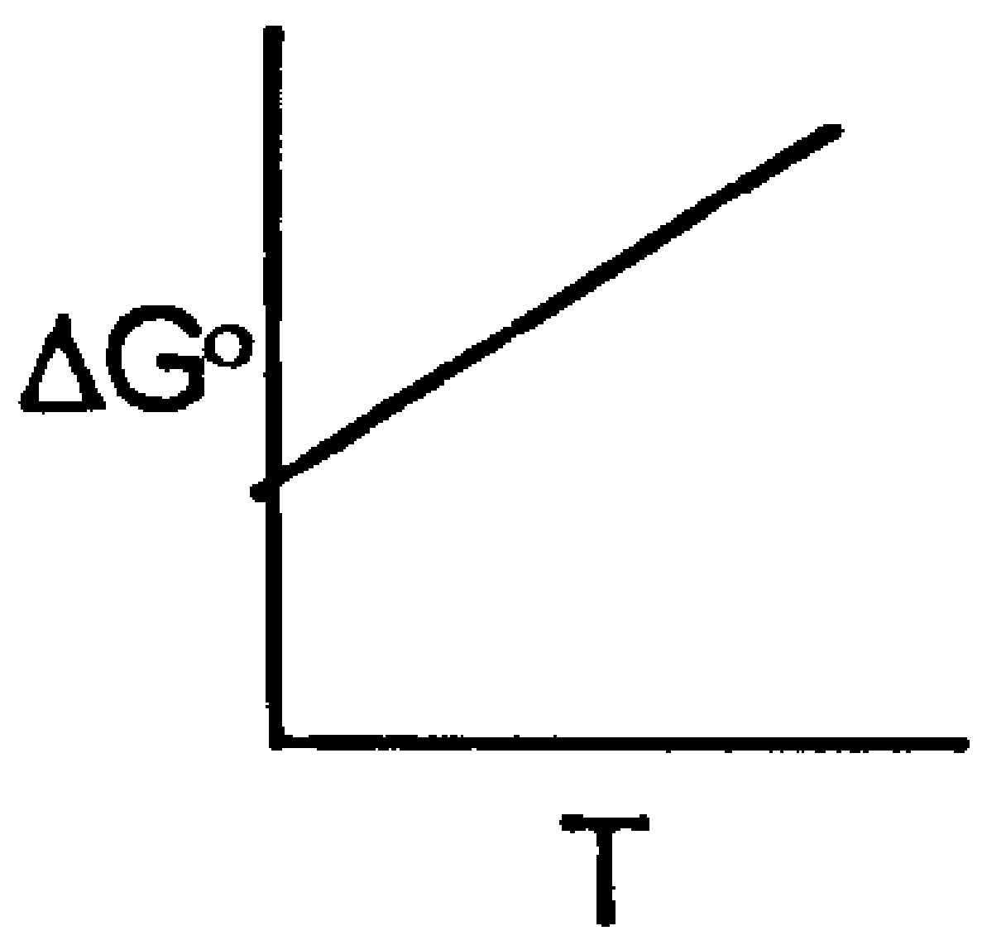
There is a perfect gas in a vessel (A) at a particular temperature. The volume of vessel is doubled (B) *isothermally* (means temperature stays the same).

What do you think about the internal energy change of the gas? Explain as carefully as you can.

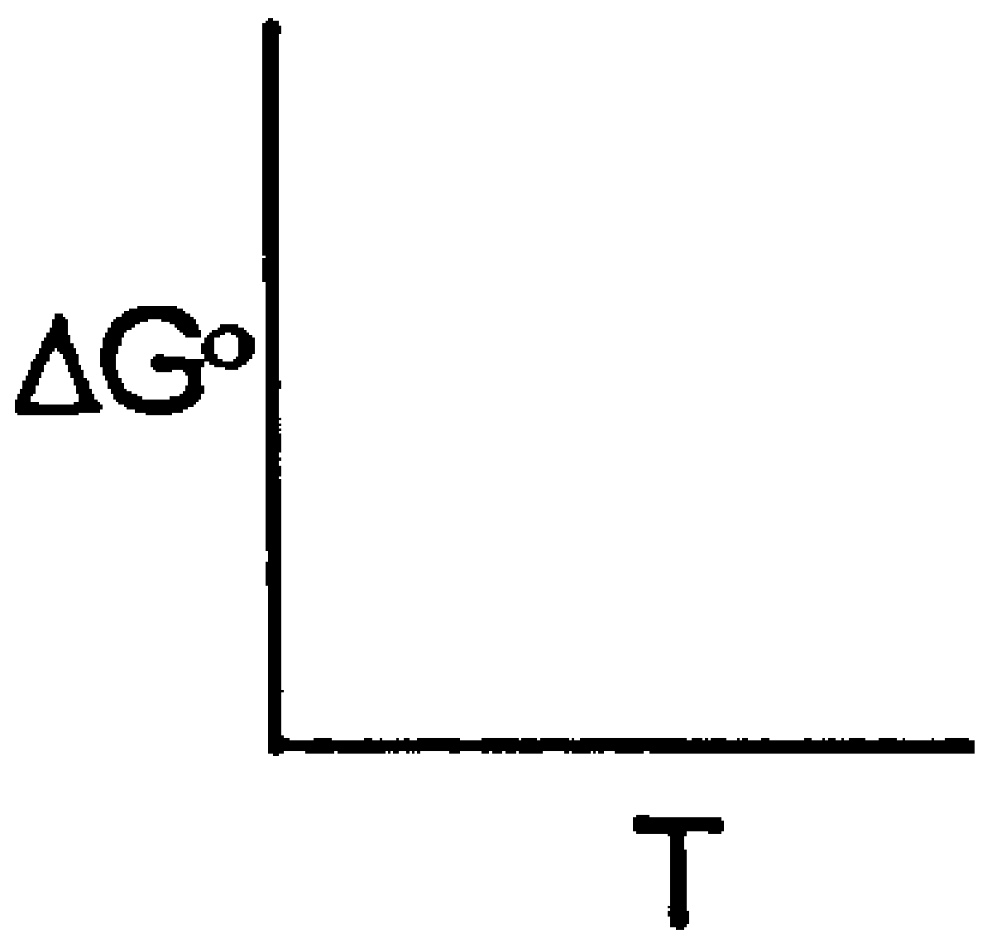
ΔG^{0} and Temperature Change

Which of the following diagrams best represents the change in the reaction standard Gibbs free energy when the temperature increases for the following reaction?

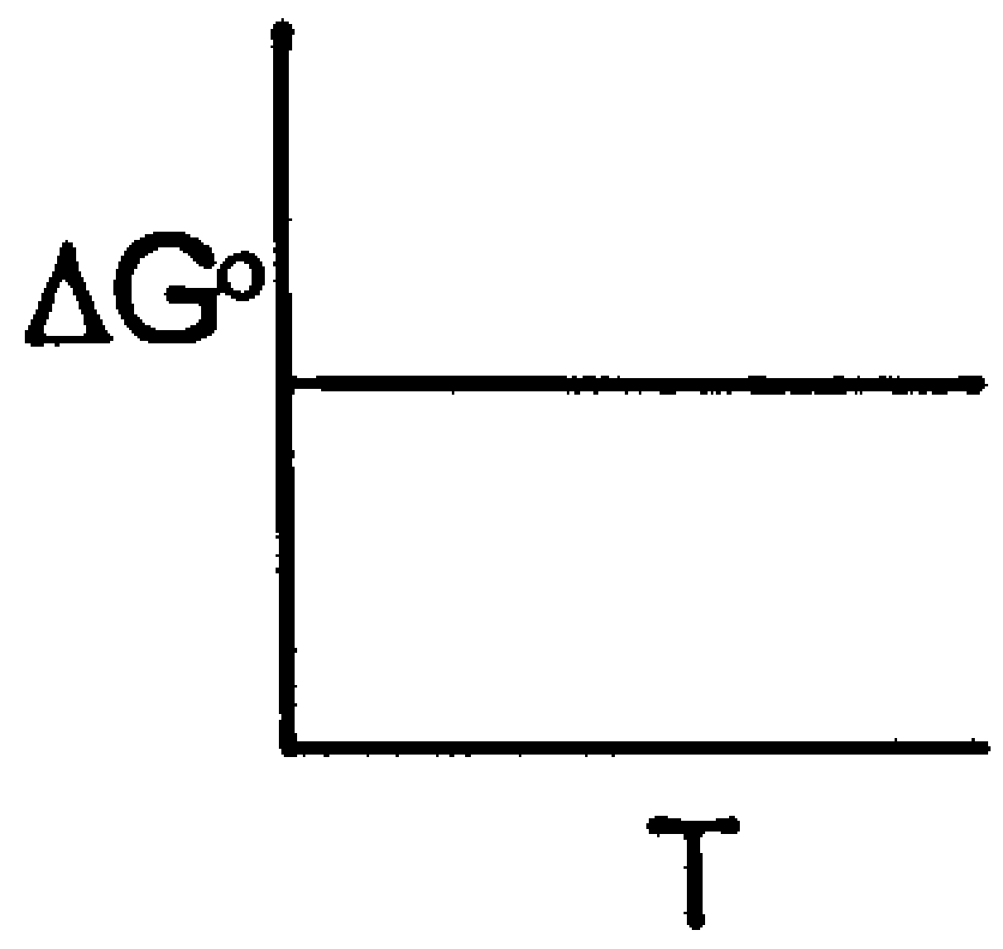
$$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$$



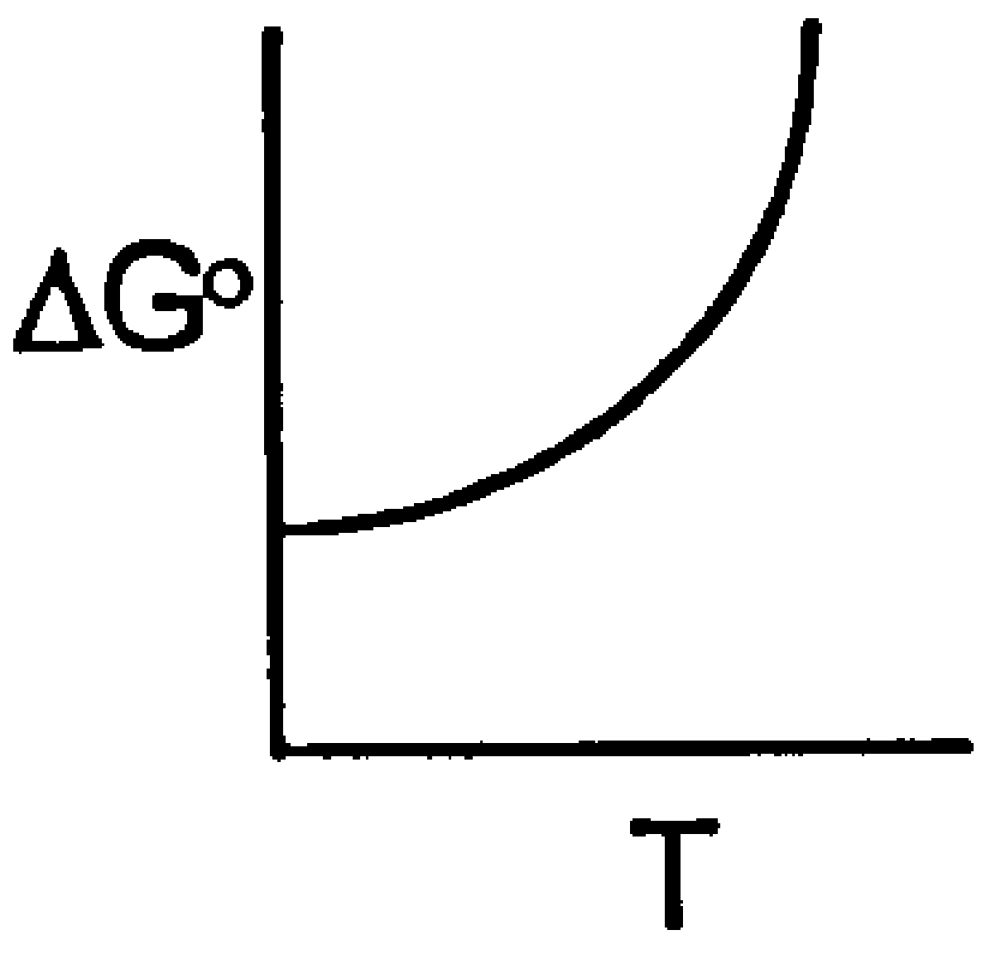
(a)



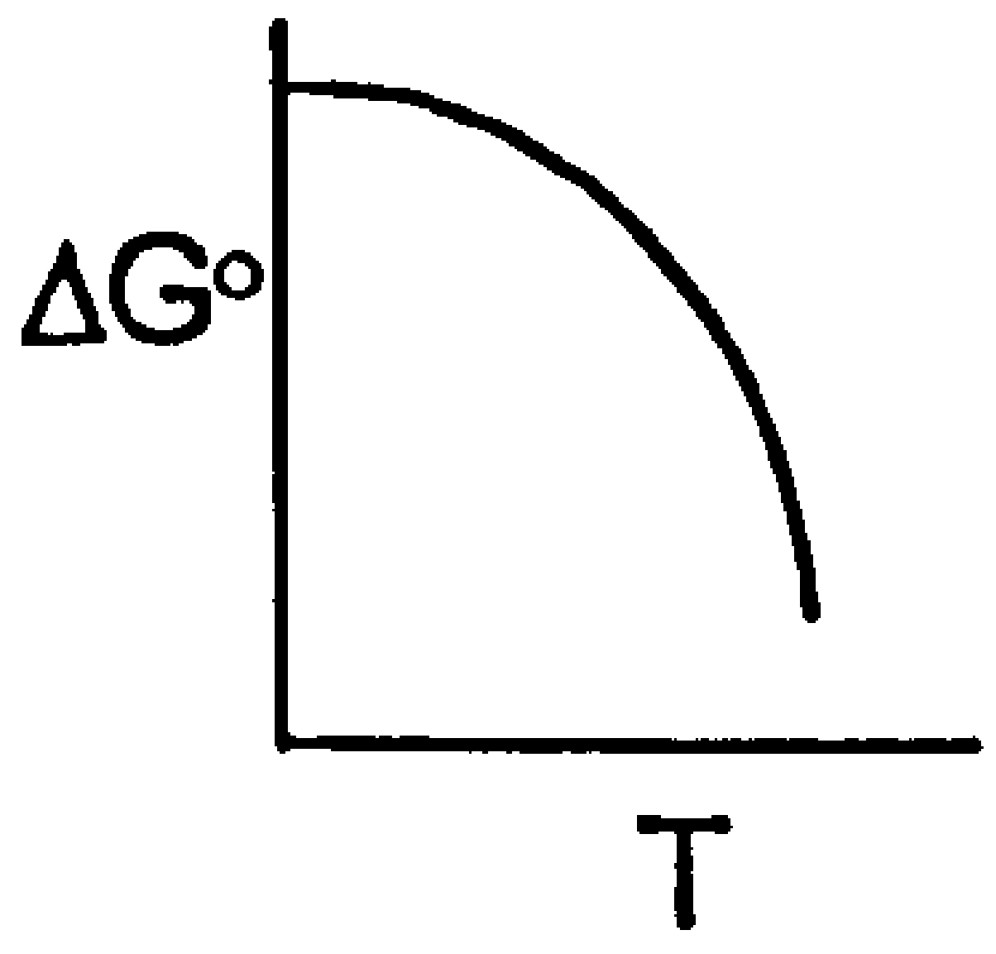
(b)



(c)



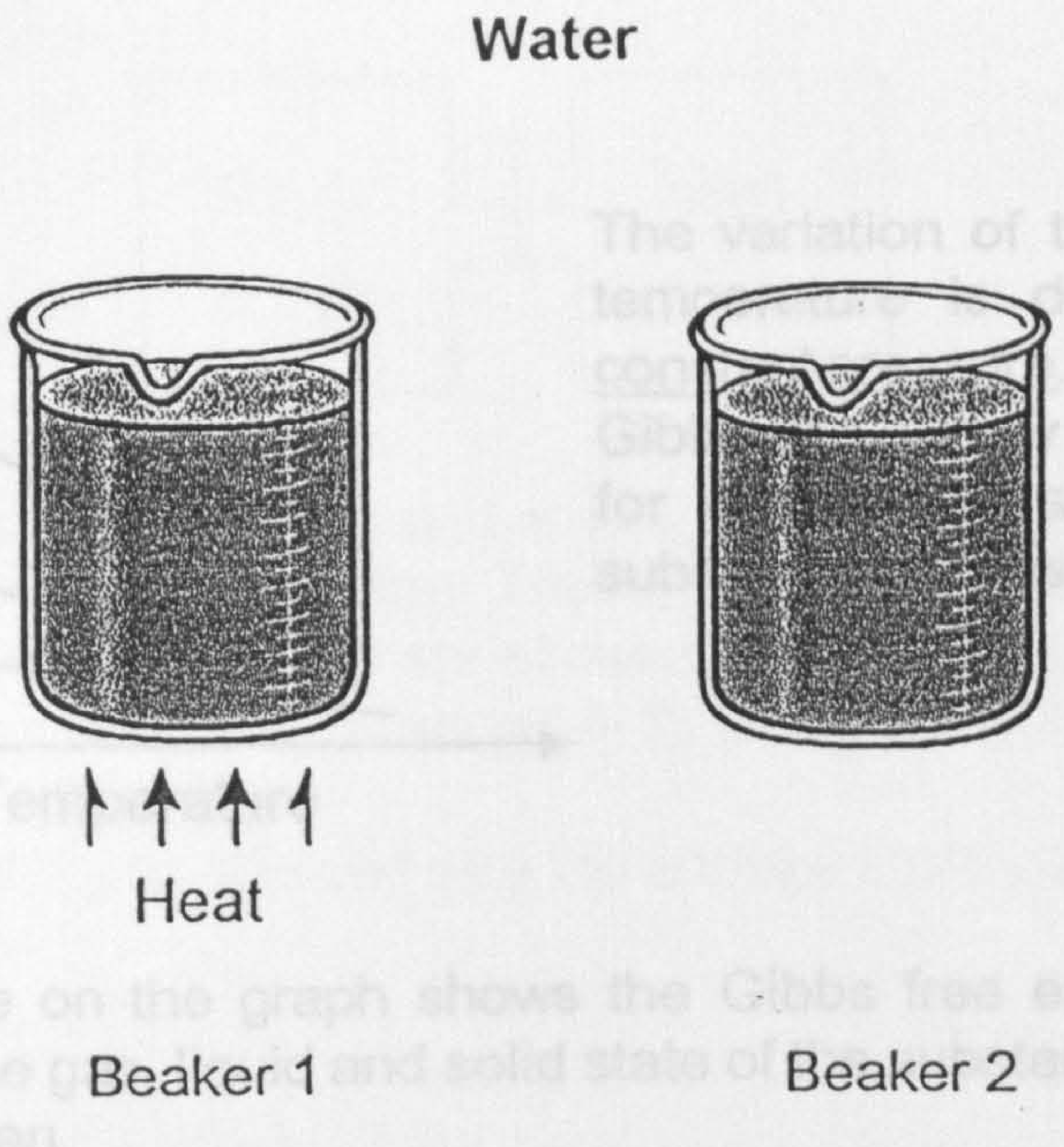
(d)



(e)

Diagram ....best represents the standard Gibbs free energy change when the temperature increases.

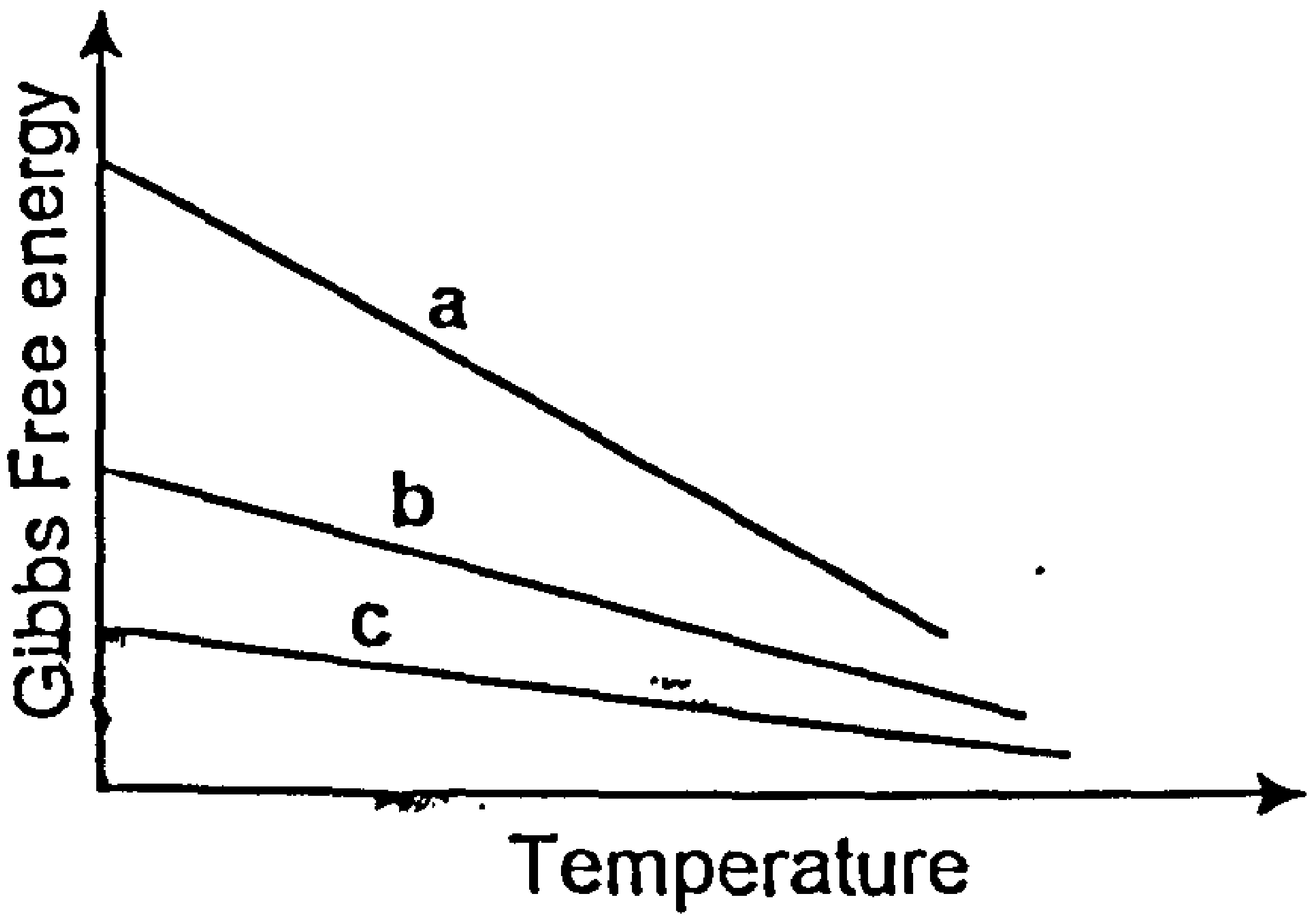
Explain your answer as carefully as you can.



Two identical 1 litre glass beakers each contain 900 cm^3 of water. At the starts, both beakers are at room temperature (25 ^oC). Later, Beaker 1 is heated by a candle for five minutes while Beaker 2 is stirred vigorously at room temperature for five minutes.

How will the final internal energies of the two beakers and their contents compare with their initial internal energies? Explain your answer as carefully as you can.

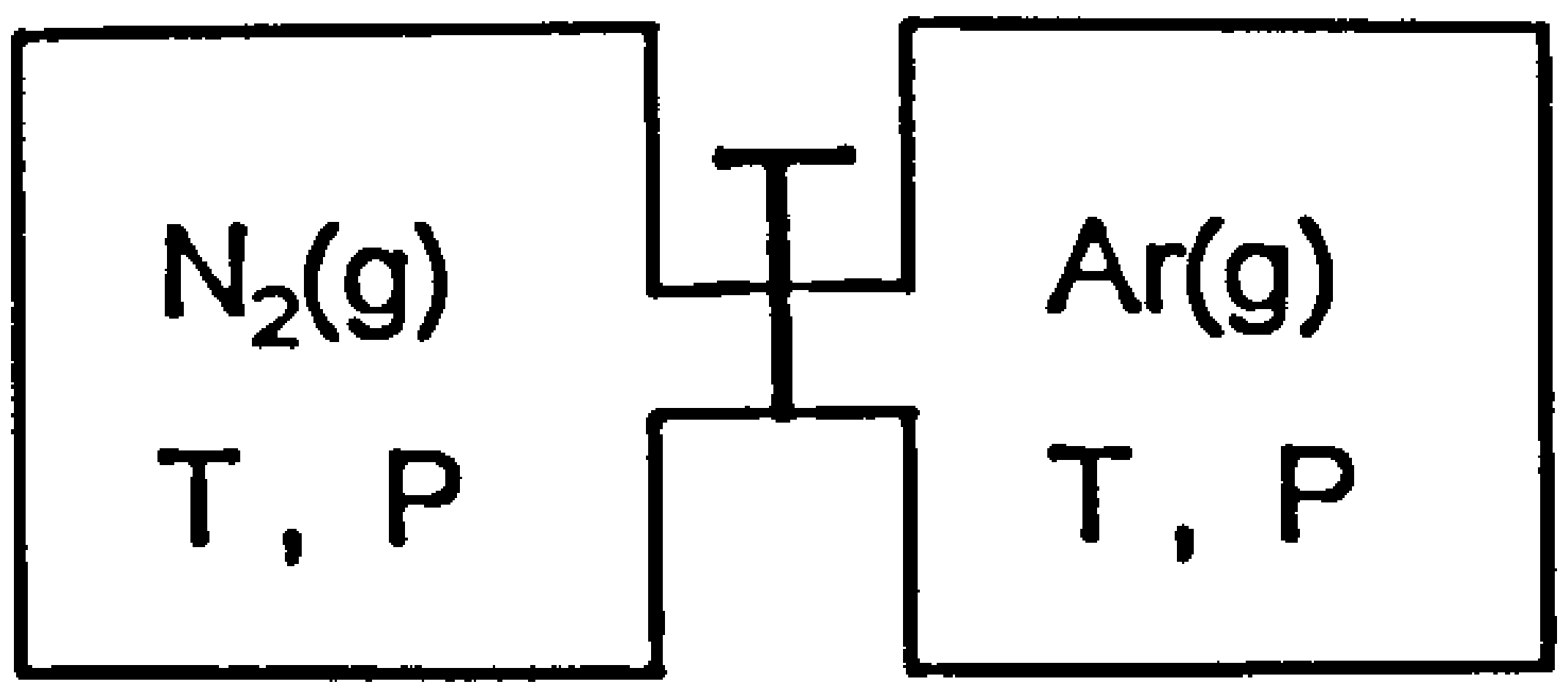
Gibbs Free Energy Change with Temperature



The variation of the Gibbs free energy with the temperature is determined by the entropy at constant pressure. The graph shows the change in Gibbs free energy when the temperature increase for gas, liquid and solid states of the same substance at constant pressure.

Decide which line on the graph shows the Gibbs free energy changes with increasing temperature for the gas, liquid and solid state of the substance and explain your answer as carefully as you can.

Mixing of the Gases



Imagine that two gases, nitrogen and argon, placed in equal volume containers which are connected with each other by a tap. Their initial pressures are P. At constant temperature the tap is opened and two gases are allowed to mix. After the mixing, the entropy of gases increases and their final total pressure is P. Using these information:

a) Explain as carefully as you can why the entropy increases.

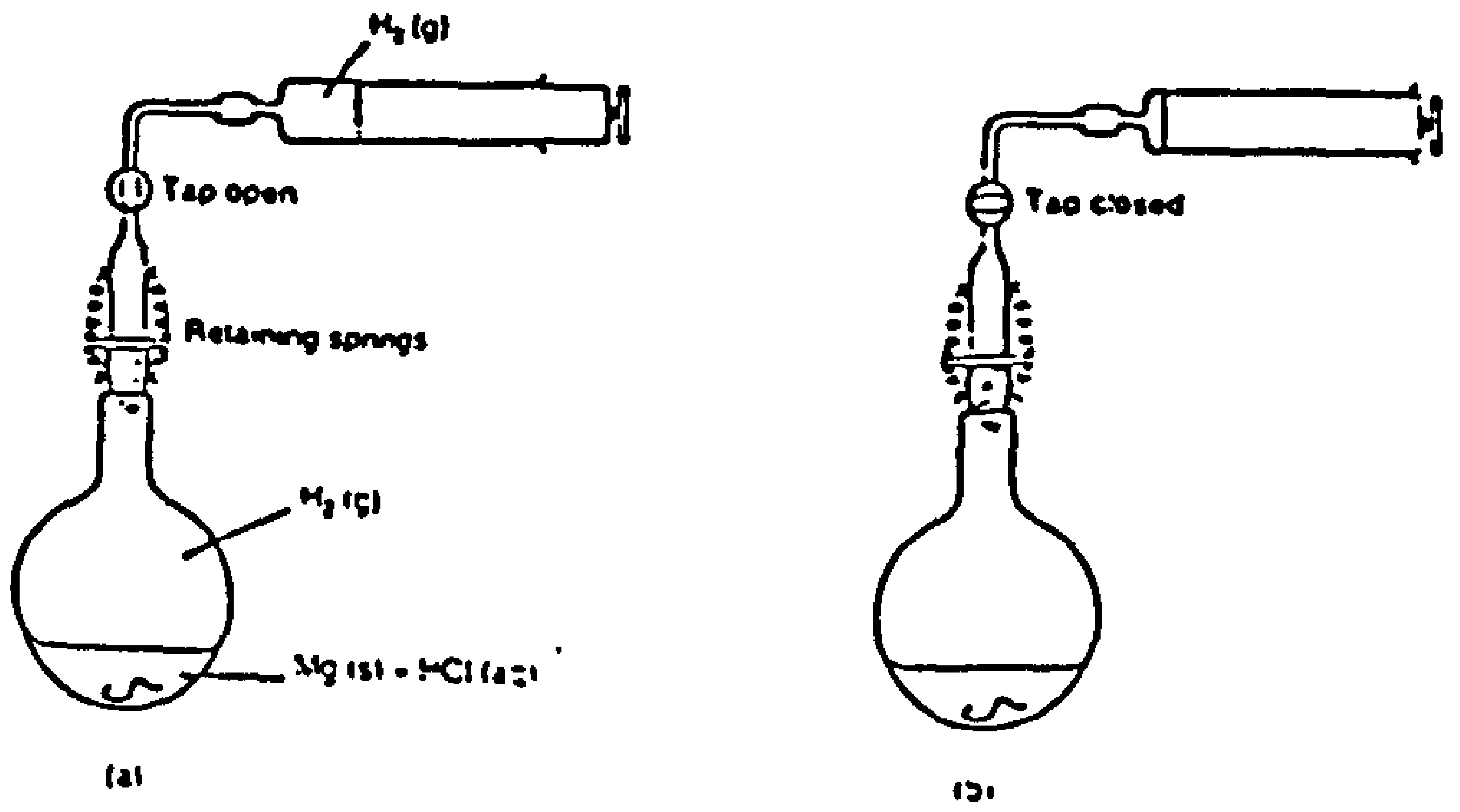
b) Estimate how the enthalpy of the gases changes, and explain your answer as carefully as you can.

c) Estimate how the Gibbs free energy of the gases changes, and explain your answer as carefully as you can.

Magnesium

Consider the same reaction

$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta H = -463\ kJ\ mol^{-1}$$



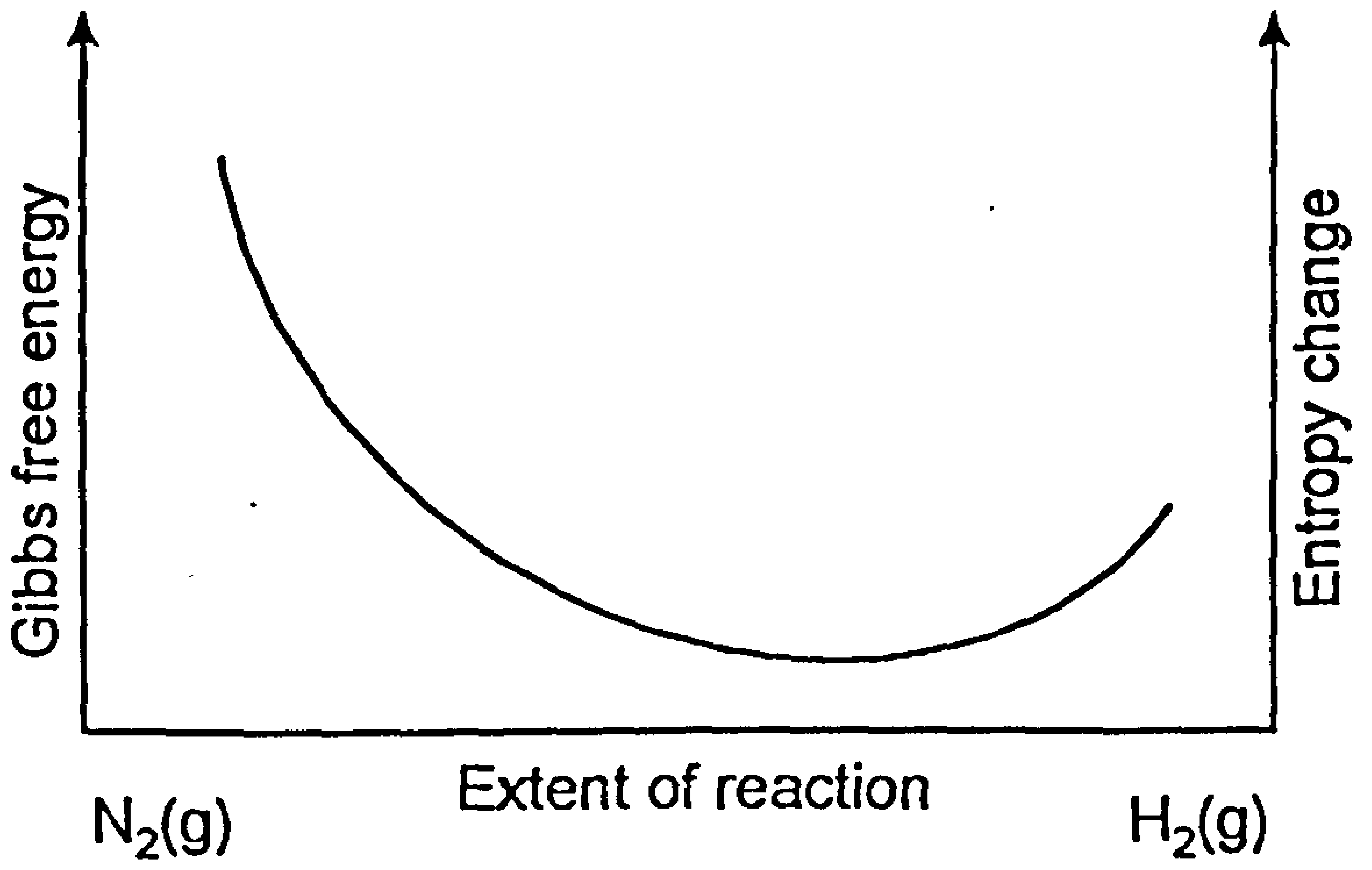
taking place in each set of apparatus shown here. In **a** the tap is open; in **b** tap is closed, and equal amounts of reactants are used in each case.

Consider that the reactions are completed and the systems are cooled down to the beginning temperature. Suppose that it is possible to measure the heat given out to the surroundings.

a) In which set of apparatus do you think most heat given out to the surroundings? Explain your answer as carefully as you can.

b) Decide that in which set of apparatus heat change equals to the reaction enthalpy change and internal energy change. Explain your answer as carefully as you can.

Gibbs Free Energy Change



The graph shows the Gibbs free energy changes during the Haber process reaction;

$$N_2(g) + 3\,H_2(g) \leftrightharpoons 2\,NH_3(g)$$

On the same graph draw the total entropy changes of during the process and explain your answer as carefully as you can.

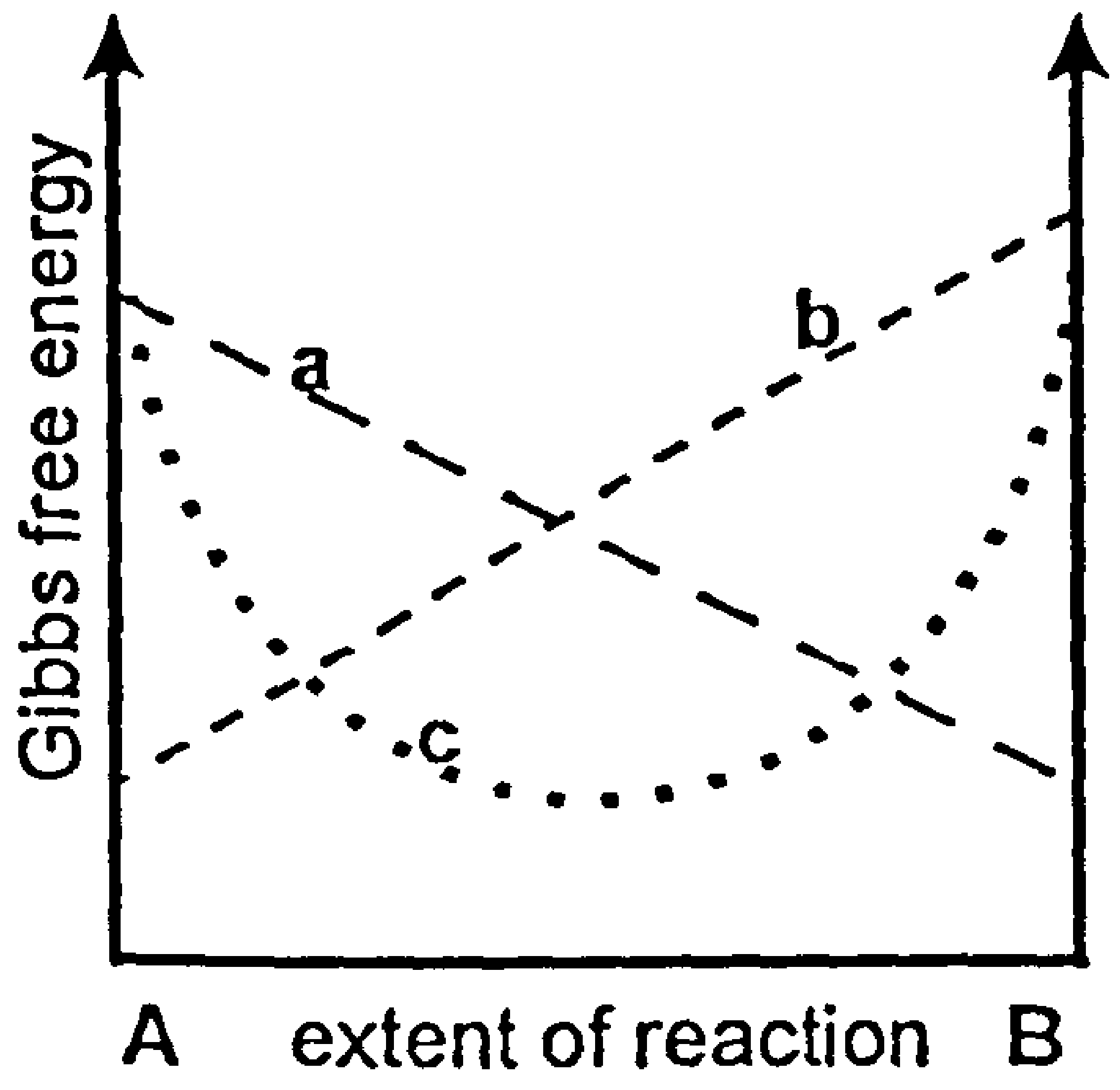
Hypothetical Reactions

The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1	$A + B \rightarrow C + D$	Exothermic
Reaction 2	$E + F \rightarrow G + H$	Endothermic

What do you think about the rate of the reactions? Explain your answer as carefully as you can.

Gibbs Free Energy

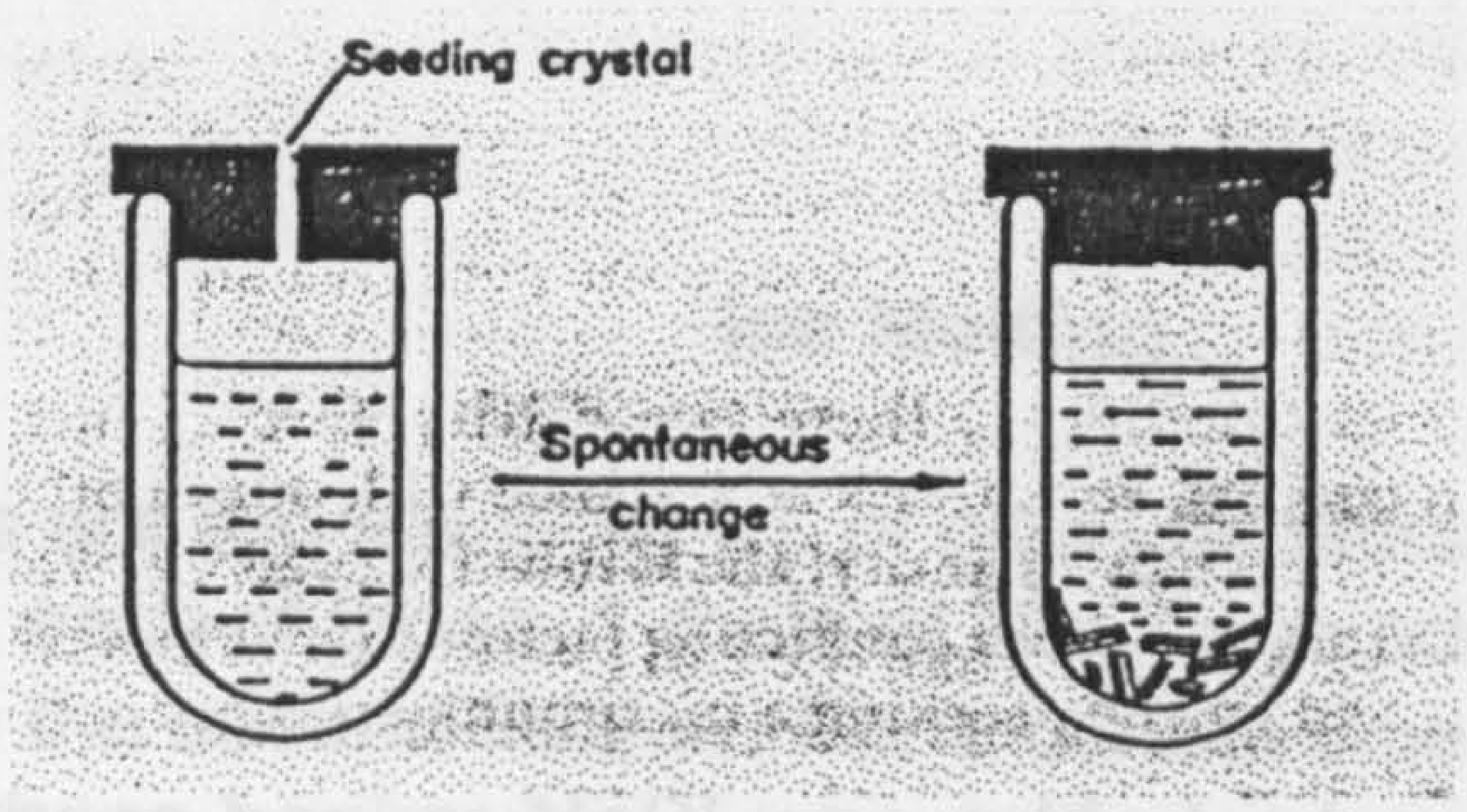


Students were asked to draw a graph of Gibbs free energy versus extent of reaction for the reaction

A ⇆ B . The following graph shows the three of students drawings.

Which graph do you think represents the Gibbs free energy changes versus extent of reaction. Explain your answer as carefully as you can.

Spontaneous Change



A saturated hot solution of sodium thiosulphate is allowed to cool slowly. If care has been taken to keep the materials clean and dust free , supercooling by several degrees is possible. The solution is then sealed in a Dewar flask which does not allow to energy transfer between system and surrounding. On dropping a tiny seeding crystal through a hole in the lid (see figure) crystallization occurs, with an apparent increase of organisation.

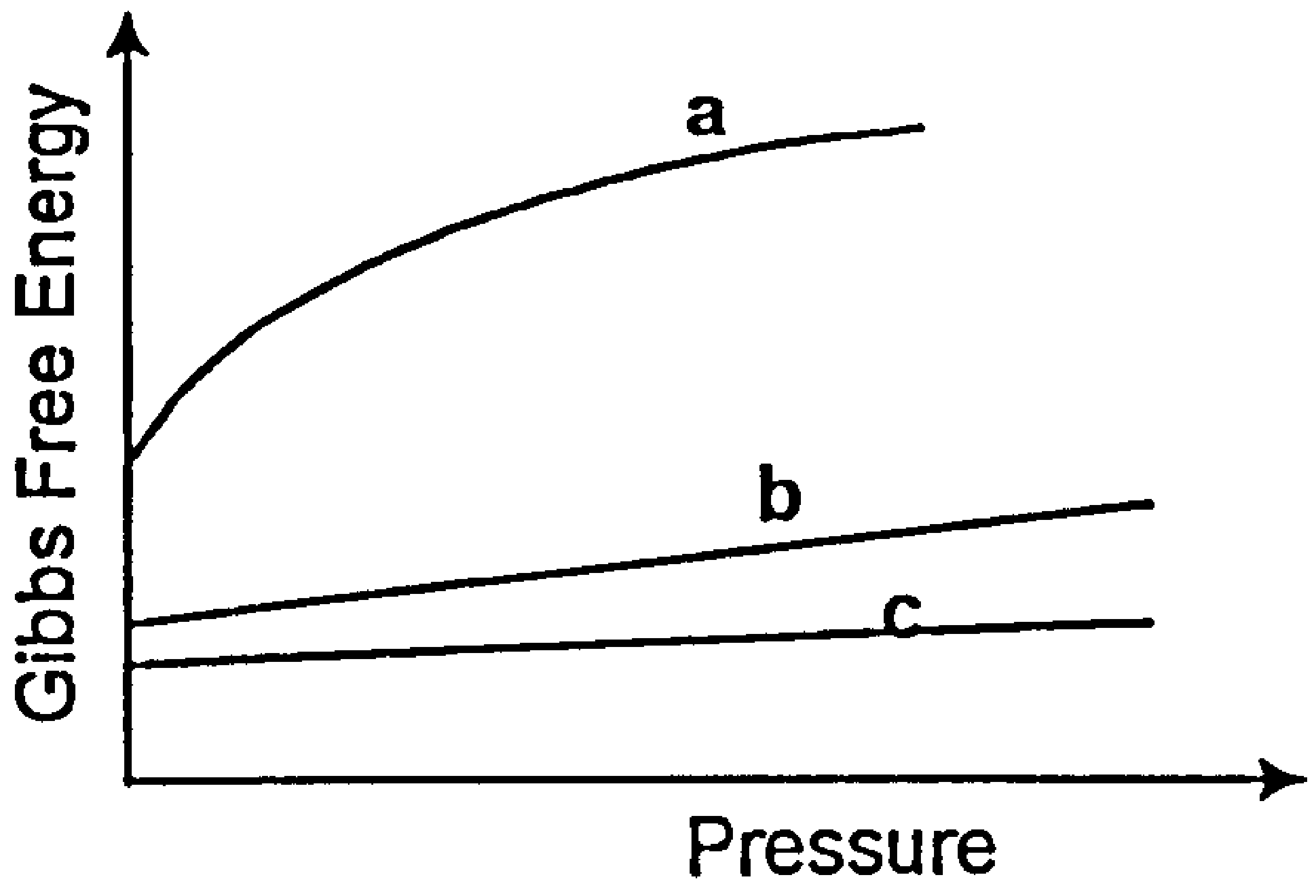
What do you think will happen to the entropy of the system when the crystals form? Explain your answer as carefully as you can.

Ice Melting

Consider that there are two identical 1 L of glass beakers contain 300 mL of water and 250 g of crushed ice in each of those. 1 mole of NaCl was added to the first beaker and 1 mole of KI was added to the second beaker. For a certain time later, it was observed that the ice melted quickly in those beaker NaCl was added, whereas there were more ice in those beaker KI was added.

Using this information, decide that which salt need more energy when they dissolved in water. Explain your answer as carefully as you can.

Gibbs Free Energy Change with Pressure

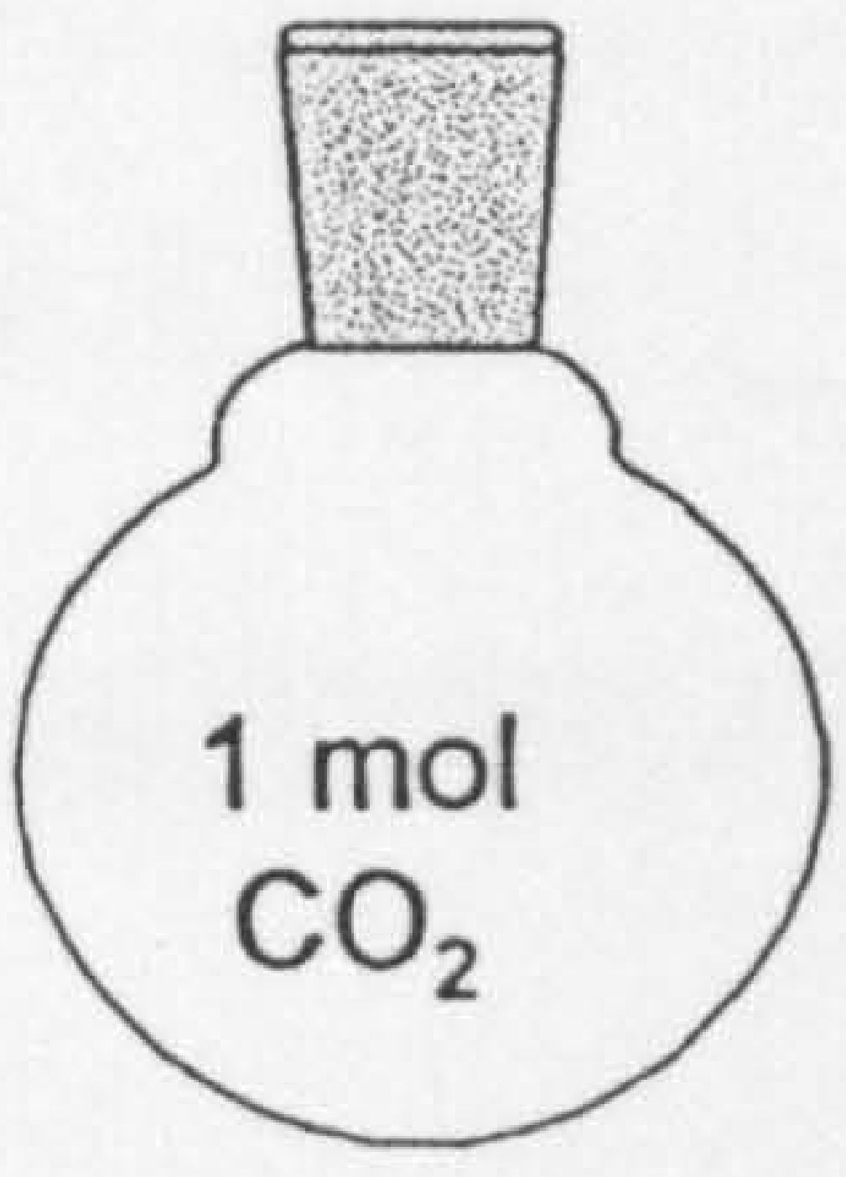


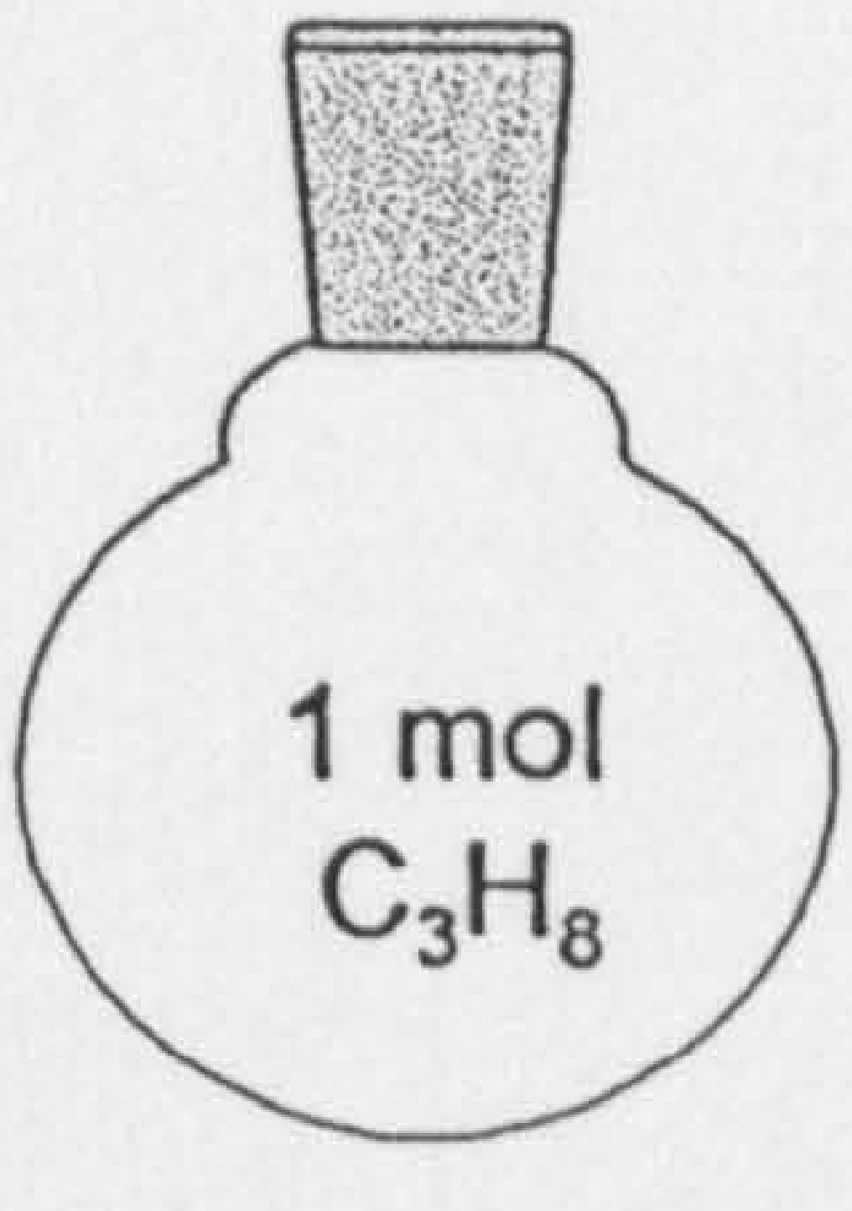
The variation of the Gibbs free energy with the pressure is determined by the volume of the sample at constant temperature. The graph shows the change in Gibbs free energy with the increasing pressure at constant temperature for the gas, liquid and solid states of the same substance.

The line **a, b, c** represents the Gibbs free energy change with increasing pressure for the gas, liquid and solid phase of the same substance. Explain as carefully as you can why the Gibbs free energy change for the gas phase of the substance is higher than that of liquid and solid phase.

Carbon Dioxide and Propane

Carbon dioxide and propane gases have the same molar mass. There are two identical glass balloon one of those is fulled with 1 mole of carbon dioxide gas and the other is fulled with 1 mole of propane gas are shown below.





Which gas do you think has the greater entropy value ? Explain your answer as carefully as you can.

Appendix 3

Pre-Test -I

Name:________________

Date:_________________

Department:____________

AN INVESTIGATION *on* CHEMISTRY UNDERGRADUATES' UNDERSTANDING of INTERNAL ENERGY, ENTHALPY, ENTROPY AND GIBBS ENERGY

(Pre-Test - I)

Time Required : Approximately 50 minutes

Before you start please read the letter on the next page.

Mustafa SOZBILIR

Department of Educational Studies
University of York
York YO10 5DD

Dear Student,

You may be wondering why you are being asked to complete this test!

I am a researcher working on a research project to find out university chemistry students' ideas about some aspects of chemistry. The study is taking place over three years. Similar questions will be given to you at the end of this academic year to complete again. Your responses to the questions will help tutors and lecturers gain a better understanding of the some ideas of the thermochemistry students find difficult.

The test is designed to reveal what chemistry students really understand. You are encouraged to give your own ideas. I am asking you to answer honestly. If you are not able to answer the question, don't panic! This is not an exam. You don't need to force yourself to give an answer. Don't look for tricks (none is intended) and lengthy answers are not expected.

If you are not able to give an answer to a question pass on to the next question. Don't spend too long time on any one. 5 minutes should be enough for each question.

Unfortunately, I am not be able to give answers or discuss any of the questions asked in the test. Of course, you may look up the answers for yourself or discuss them with your lecturer. This is because of the confidentiality of the research study. I apologise for any inconvenience about this issue.

Finally, all the responses from you and information about you will be confidential and will only be used for the research study.

I am planning to interview a small group of students to gather more information on possible areas of difficulty. These interviews will be recorded for research purposes only. If you do not want to be interviewed, please tick the box here ☐.

Thank you very much for answering the questions.

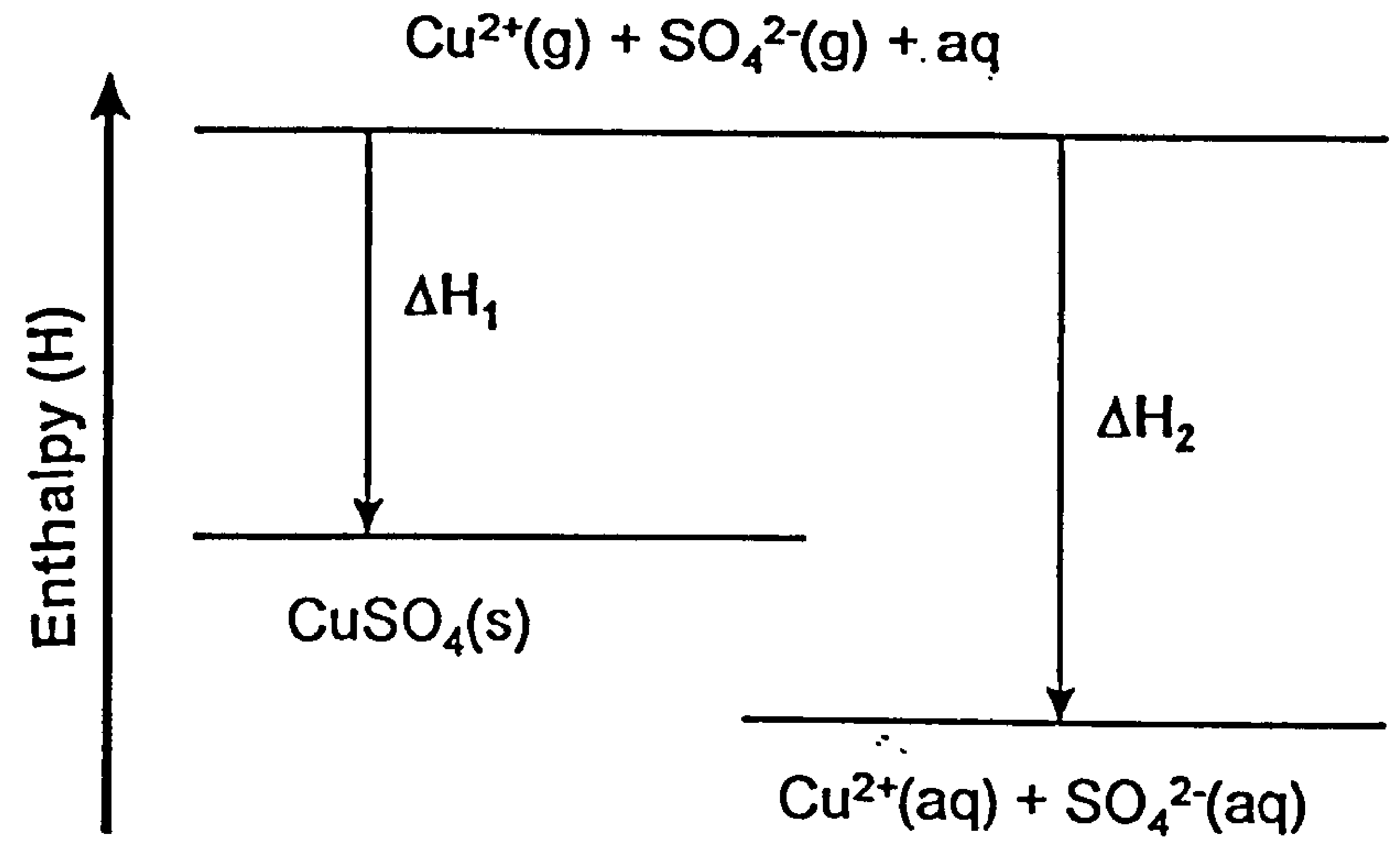
October 1998

Yours sincerely

M. SÖZBİLİR

Copper(II) Sulfate

An energy-level diagram is shown below for the dissolving of anhydrous copper (II) sulfate.



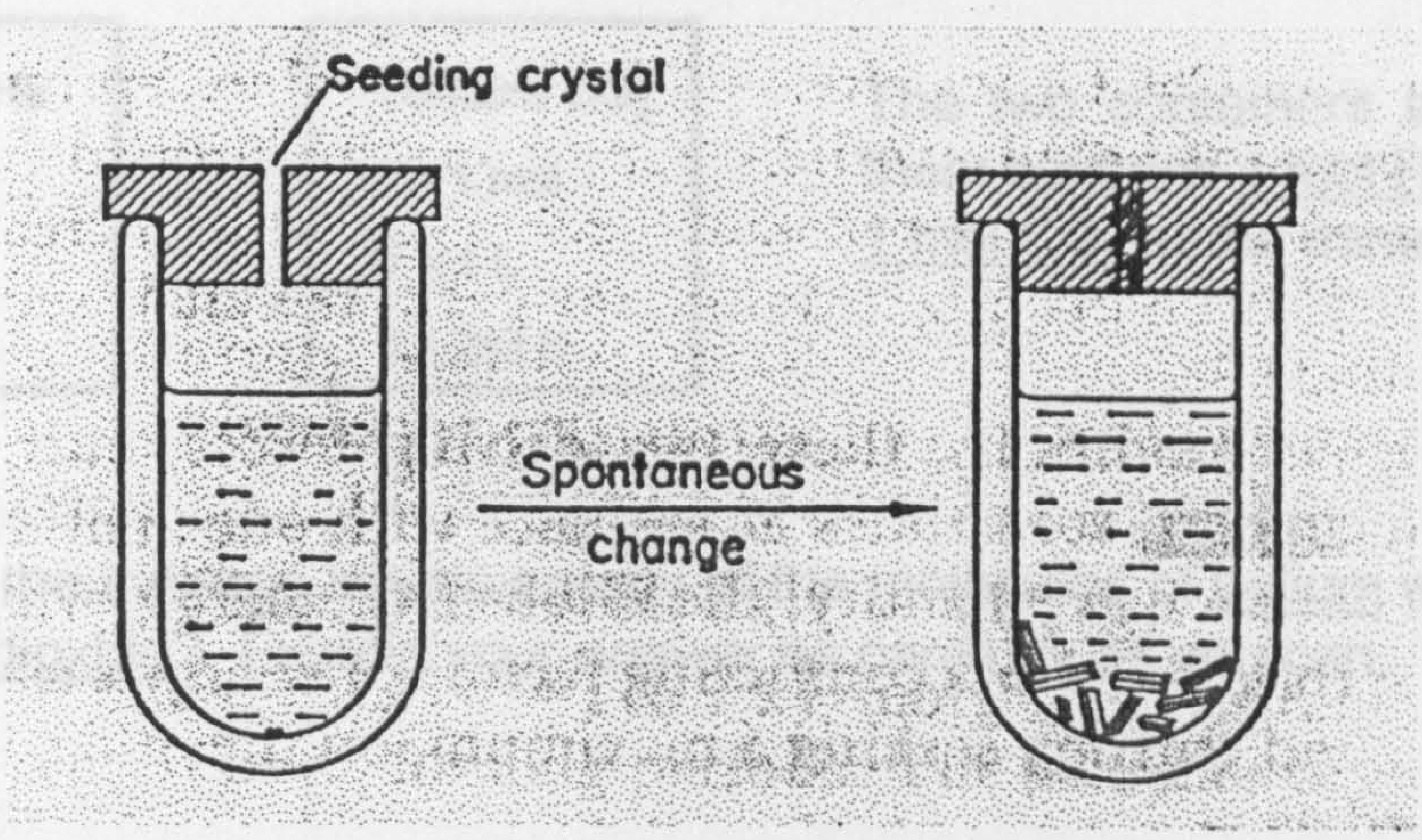
a) Write down the name of enthalpy changes indicated by ΔH_1 and ΔH_2 on the diagram into the provided gaps below.

ΔH_1 is……………………………………………, ΔH_2 is…………………………………………………

b) Draw an arrow on the diagram above to represent the enthalpy of solution ($\Delta_{soln}H$) of $CuSO_4(s)$.

c) Would you expect the temperature of the water to raise or fall when anhydrous copper(II) sulfate dissolves? Explain your answer.

Spontaneous Change



A hot saturated solution of sodium thiosulfate is allowed to cool slowly. If care has been taken to keep the materials clean and dust free , supercooling (*staying liquid below the temperature of the* freezing *point*) by several degrees is possible. The solution is then sealed in a thermally insulated flask. On dropping a tiny seeding crystal through a hole in the lid (see the figure) crystallization occurs spontaneously, with an apparent increase of organisation.

What do you think will happen to the entropy of the system when the crystals form? Explain your answer as carefully as you can.

Helium and Carbon Dioxide

a)

Contains He
n = 1 mol
V = 1 L
T = 298 K

Contains CO_2
n = 1 mol
V = 1 L
T = 298 K

The two containers are shown here. One of them contains 1 mol He and the other contains 1 mol CO_2 at the same temperature .

How does the average kinetic energy of the molecules of helium with that of the molecules of carbon dioxide? Explain your answer as carefully as you can.

b)

Contains He
n = 1 mol
V = 1 L
T = 298 K

A

Contains He
n = 1 mol
V = 0,5 L
T = 298 K

B

The two containers contain one mole of 1 mol He at the same temperature.

What do you think is the average kinetic energy of the molecules of helium in these containers. Explain your answer as carefully as you can.

Two Hypothetical Reactions

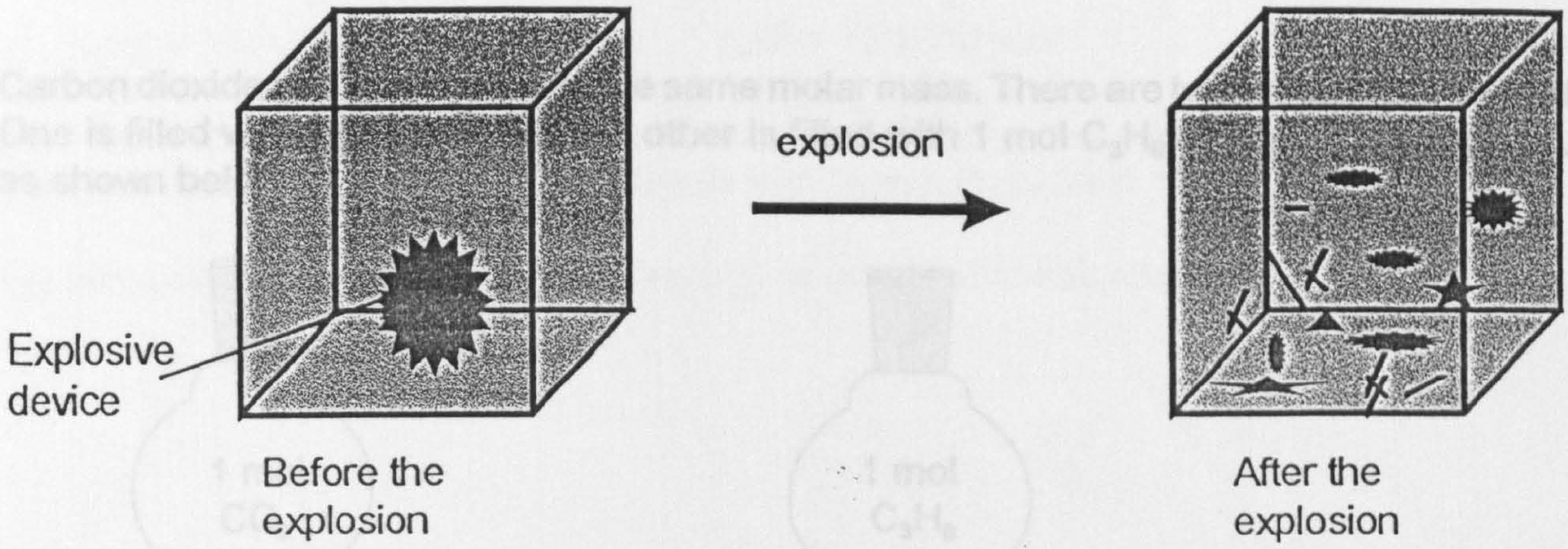
The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1	$A + B \rightarrow C + D$	Exothermic
Reaction 2	$E + F \rightarrow G + H$	Endothermic

a) On the basis of this information, can you compare the rate of these two reactions? If so, how ? Explain your answer as carefully as you can.

b) What do you think about the spontaneity of these two reactions. Explain your answer as carefully as you can.

Explosion in a Steel Box

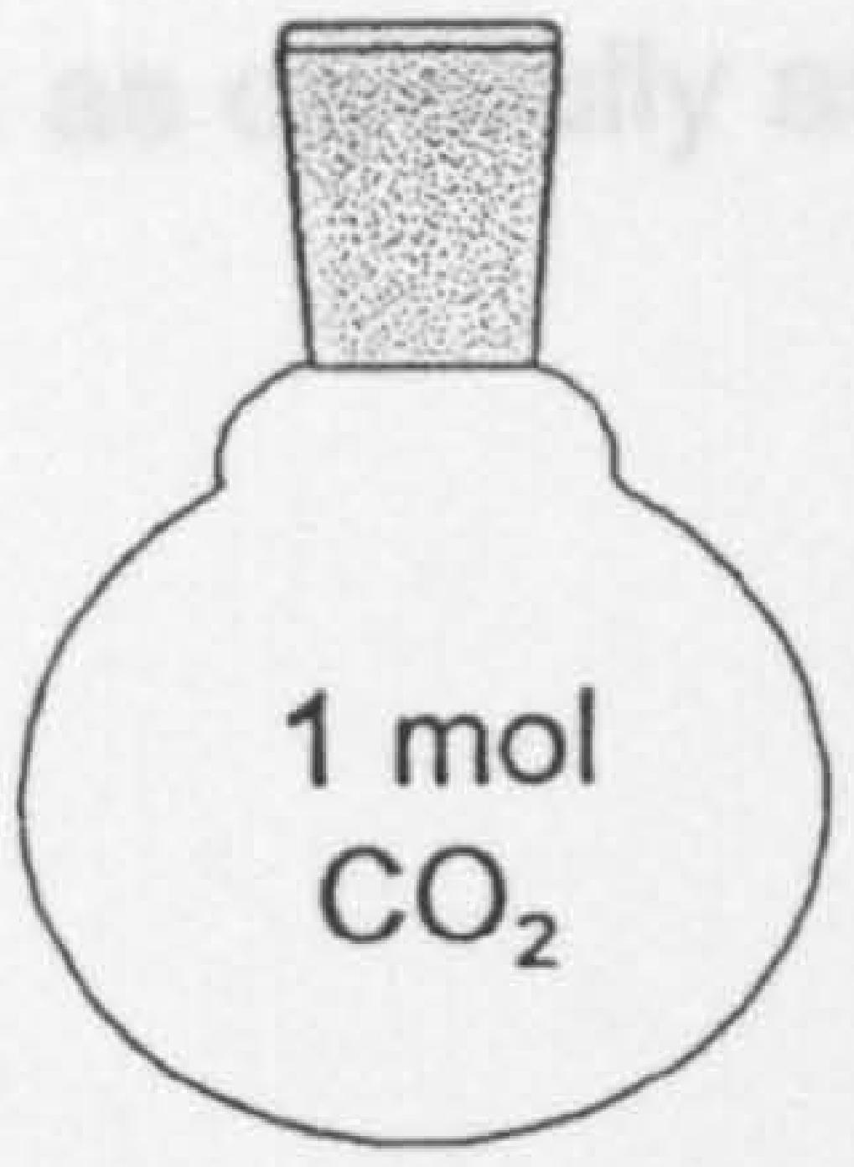


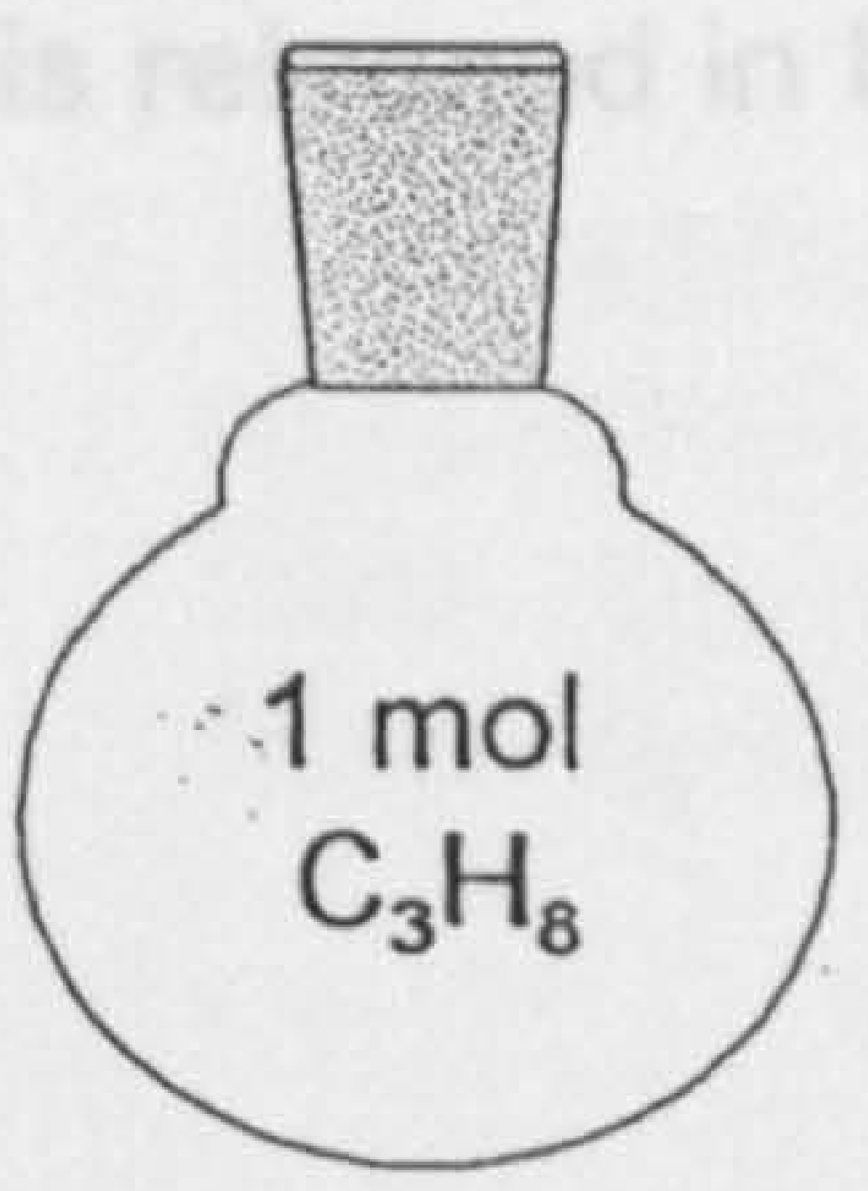
Imagine that an explosive device was placed in a thermally insulated strong steel box. Then the device is exploded within the insulated box. After the explosion, the temperature and the pressure in the box have increased. The whole system consists of the solid matters from the exploded device, the steel box and the various gases in the box.

How does the internal energy of the whole system compare before and after the explosion? Explain your answer as carefully as you can.

Carbon Dioxide and Propane

Carbon dioxide and propane have the same molar mass. There are two identical glass flasks. One is filled with 1 mol CO_2 and the other is filled with 1 mol C_3H_8 at the same temperature as shown below.





Which gas do you think has the greater entropy? Explain your answer as carefully as you can.

Energy

a) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g) \qquad \Delta_f H^\ominus = -242\ \text{kJ mol}^{-1}$

This thermochemical equation tells us that 242 kJ of energy are released as heat at constant pressure when 1 mol H_2 molecules reacts with ½ mol O_2 to form 1 mol H_2O.

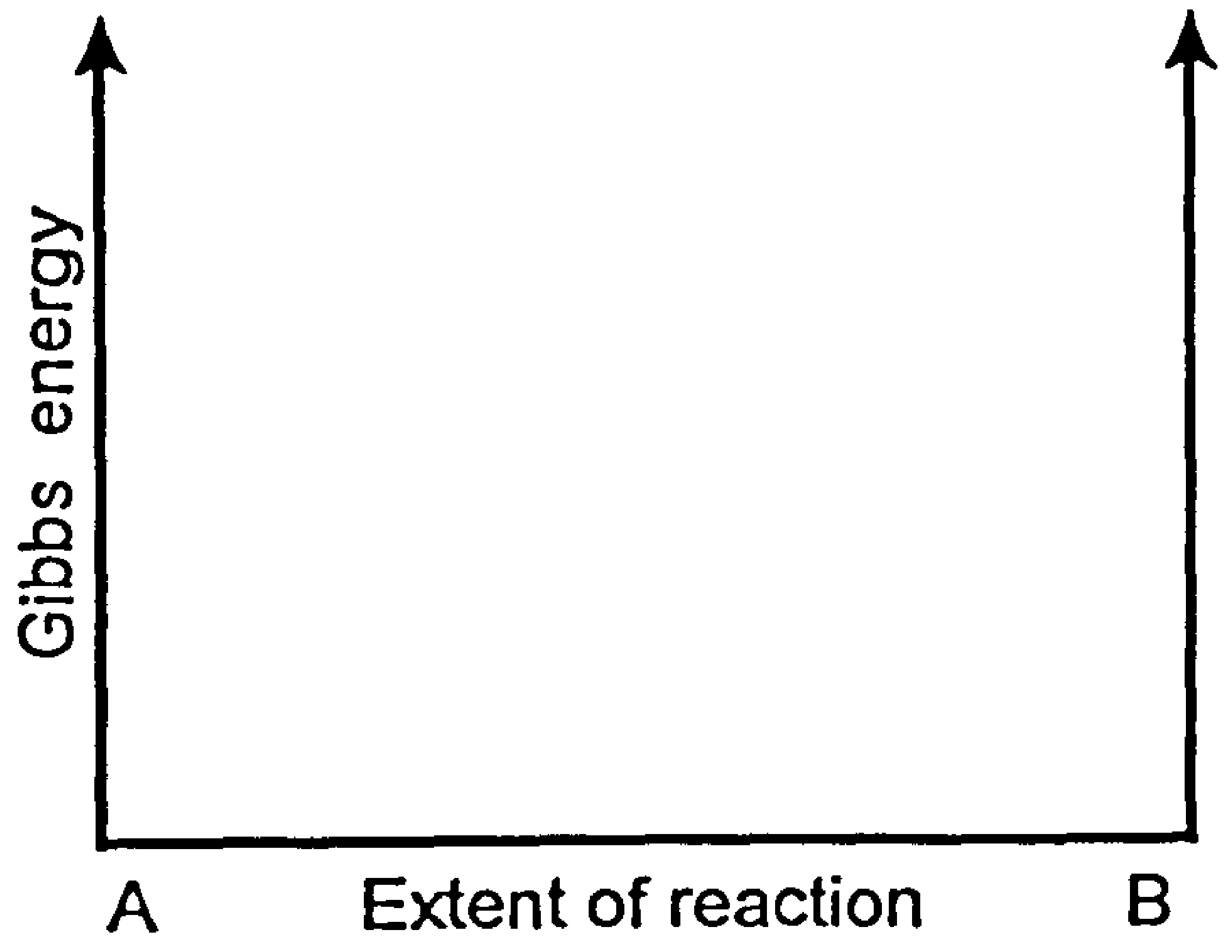
Explain as carefully as you can why energy is released in this reaction.

b) $N_2(g) + 2\ O_2(g) \rightarrow 2\ NO_2(g) \qquad \Delta_r H^\ominus = 68\ \text{kJ mol}^{-1}$

This thermochemical equations tells us that heat is required at constant pressure when 1 mol N_2 reacts with 2 mol O_2 to form 2 mol NO_2.

Explain as carefully as you can why heat is required in this reaction.

Gibbs Energy



Draw a graph of Gibbs energy versus extent of reaction A → B on the diagram is shown here. Discuss and interpret the graph as carefully as you can.

Appendix 4

Pre-Test -II

Name:________________

Date:__________________

Department:____________

AN INVESTIGATION *on* CHEMISTRY UNDERGRADUATES' UNDERSTANDING of INTERNAL ENERGY, ENTHALPY, ENTROPY AND GIBBS ENERGY

(Pre-Test - II)

Time Required : Approximately 50 minutes

Before you start please read the letter on the next page.

Mustafa SOZBILIR

Department of Educational Studies
University of York
York YO10 5DD

Dear Student,

You may be wondering why you are being asked to complete this test!

I am a researcher working on a research project to find out university chemistry students' ideas about some aspects of chemistry. The study is taking place over three years. Similar questions will be given to you at the end of this academic year to complete again. Your responses to the questions will help tutors and lecturers gain a better understanding of the some ideas of the thermochemistry students find difficult.

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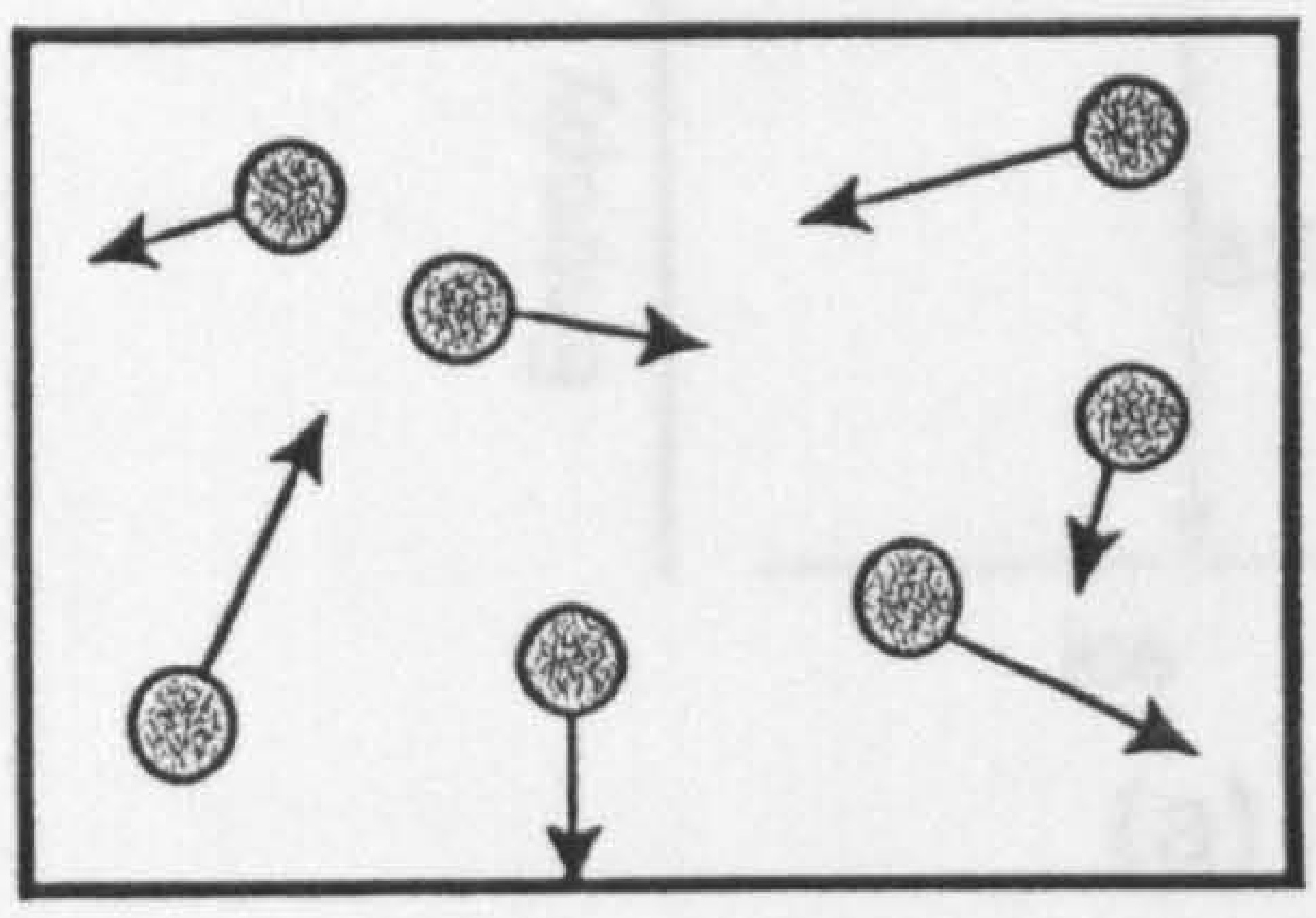
October 1998

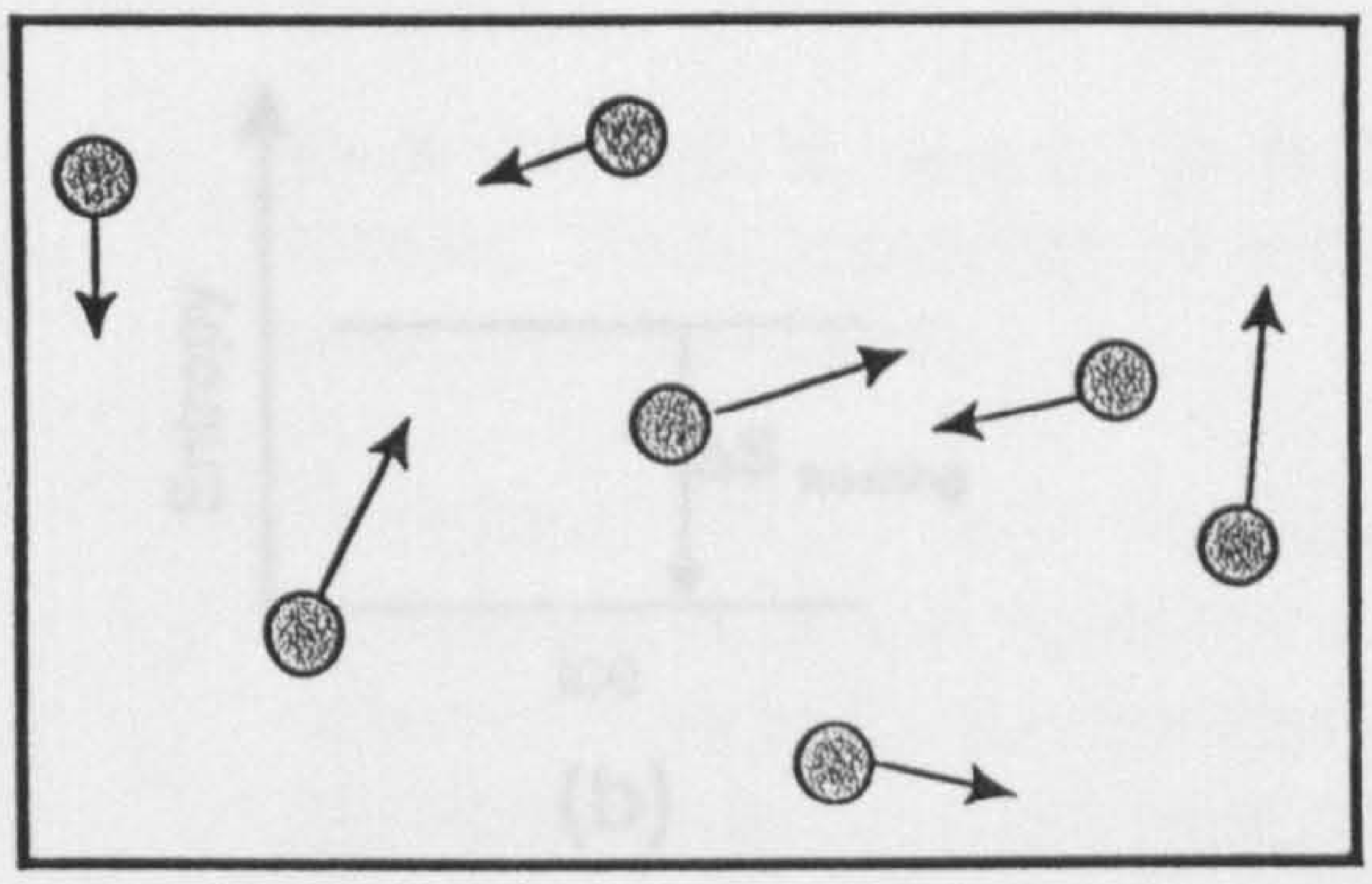
Yours sincerely

M. SÖZBİLİR

Perfect Gases



A



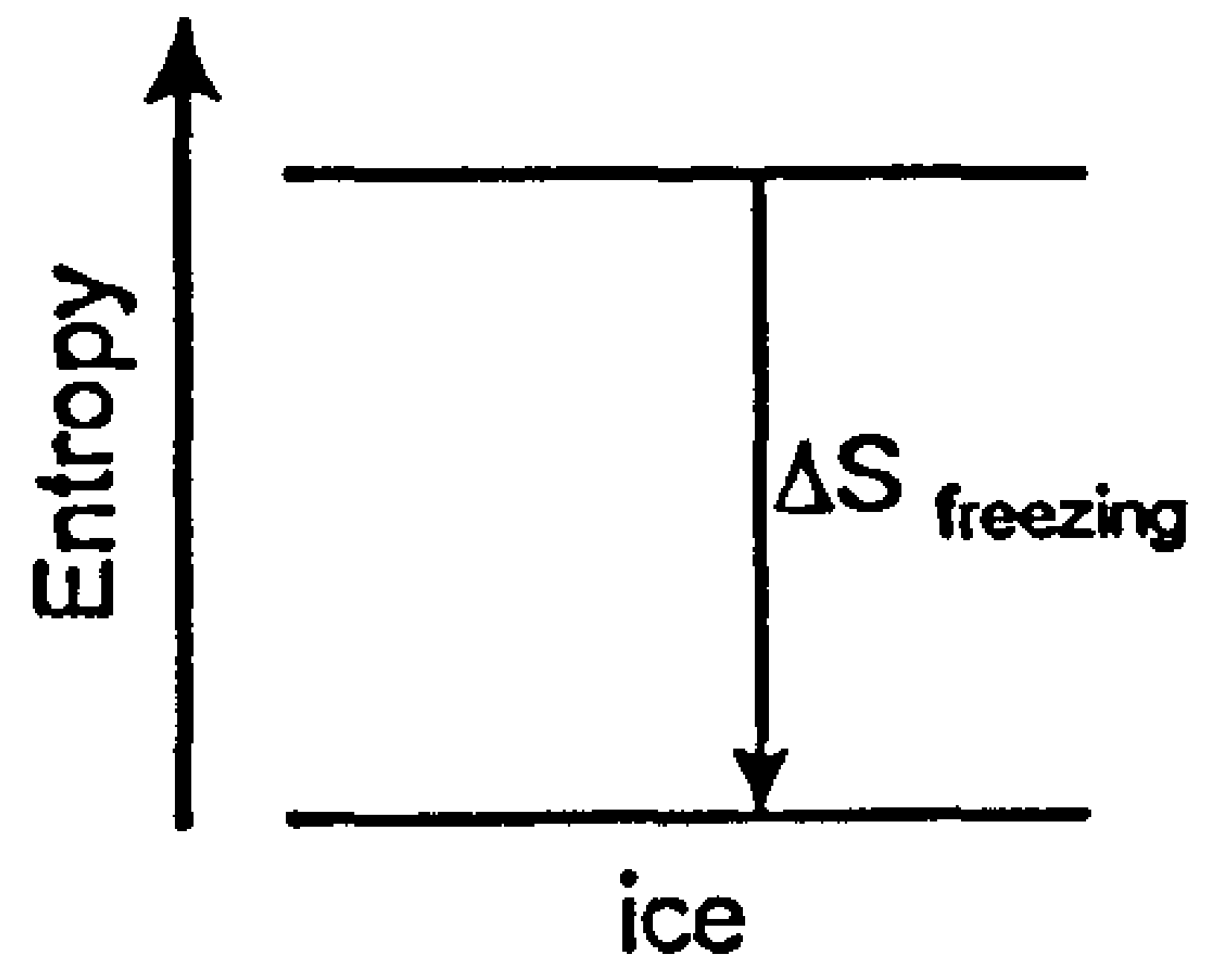
B

There is a perfect gas in a vessel (**A**) at a particular temperature. The volume of vessel is doubled (**B**) *isothermally* (this means temperature stays the same).

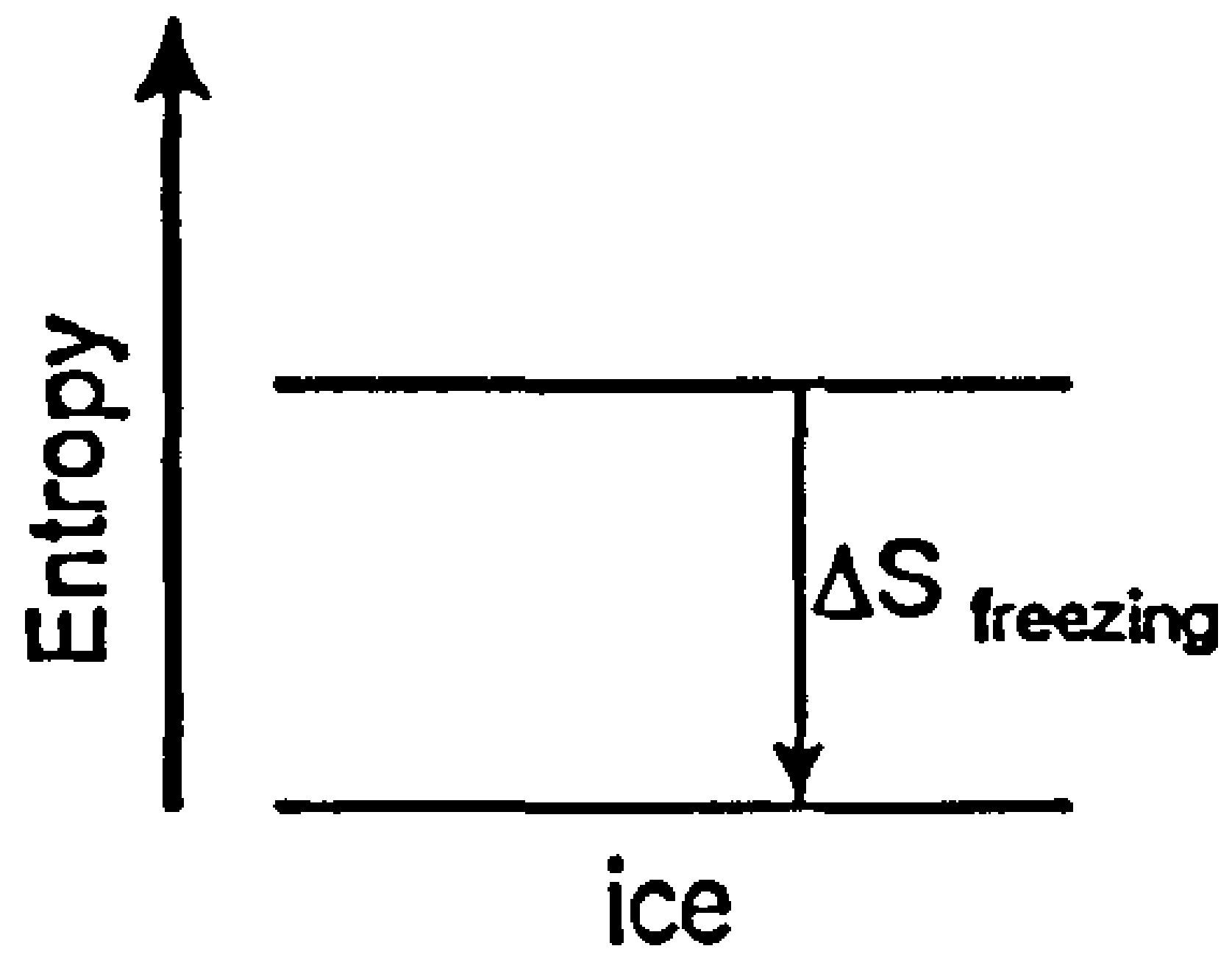
What happens to the internal energy of the gas after the expansion? Explain your answer as carefully as you can.

Seawater

Seawater contains different kinds of dissolved minerals, and therefore freezes at a lower temperature than pure water. The released energy is the same when seawater and pure water freeze. Two diagrams below show the entropy change of the freezing seawater and the pure water.



(a)



(b)

a) Decide which diagram represents the entropy change of the seawater when it freezes, and explain your answer as carefully as you can.

b) The entropy of freezing of pure water at 0 °C and 1 bar is:

$$H_2O(l) \rightarrow H_2O(s) \qquad \Delta S = -22.0\ J\ K^{-1}mol^{-1}$$

By using this piece of information, compare the magnitude of entropy change that happens in the surroundings when seawater freezes with the magnitude of entropy change that happens in the surroundings when pure water freezes at 0 °C and 1 bar.

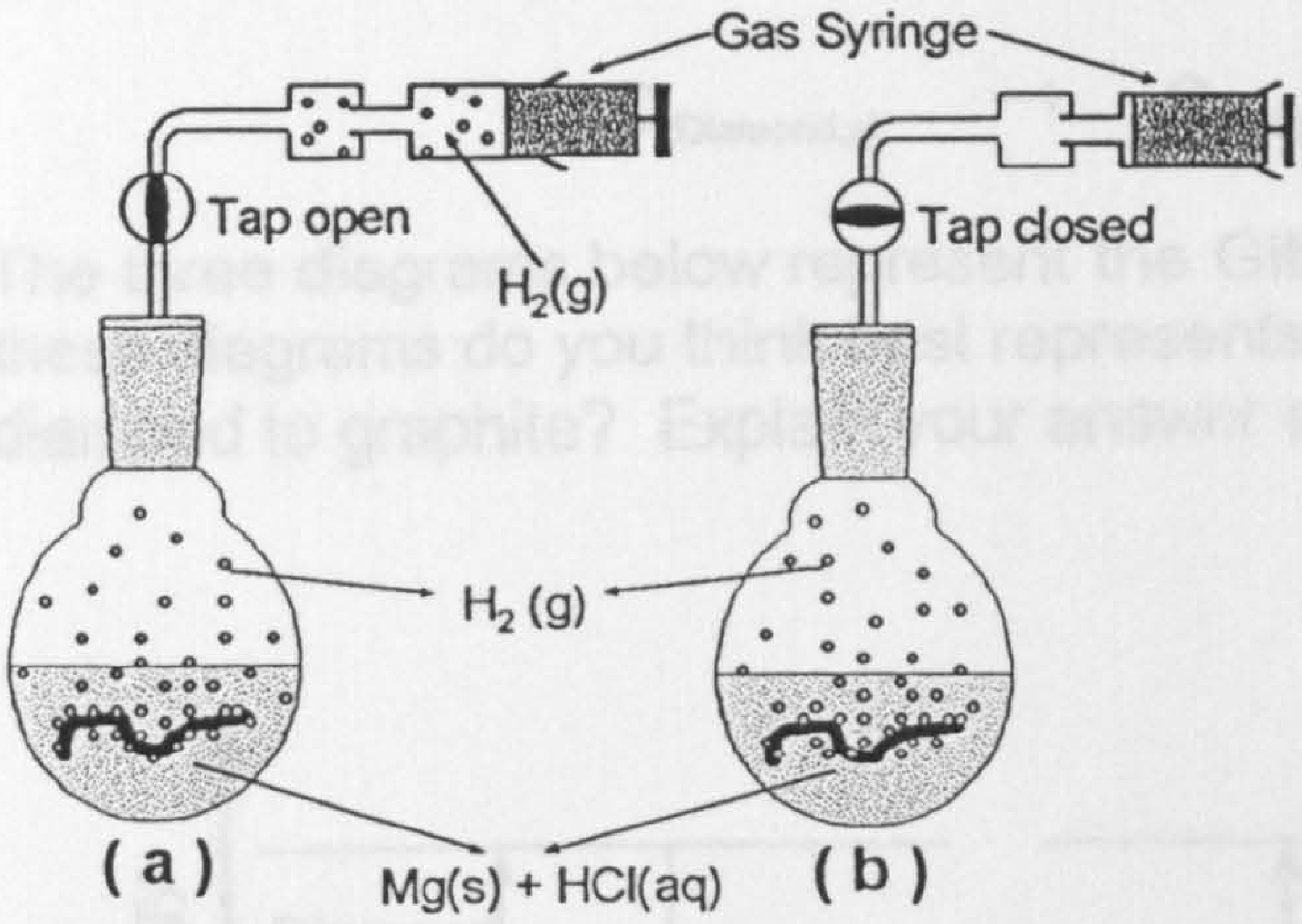
Explain your answer as carefully as you can.

Magnesium

Consider the reaction,

$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta_rH^{o} = -\,463\ \text{kJ mol}^{-1}$$

taking place in each set of apparatus shown below.



In **a** the tap is open; in **b** the tap is closed. Equal amounts of reactants are used in each case.

Consider that the reactions are completed and the systems are cooled down to their initial temperature, and you are able to measure the heat given out to the surroundings by the reaction. On the basis of this information:

a) In which set of apparatus do you think most heat is given out to the surroundings? Explain your answer as carefully as you can.

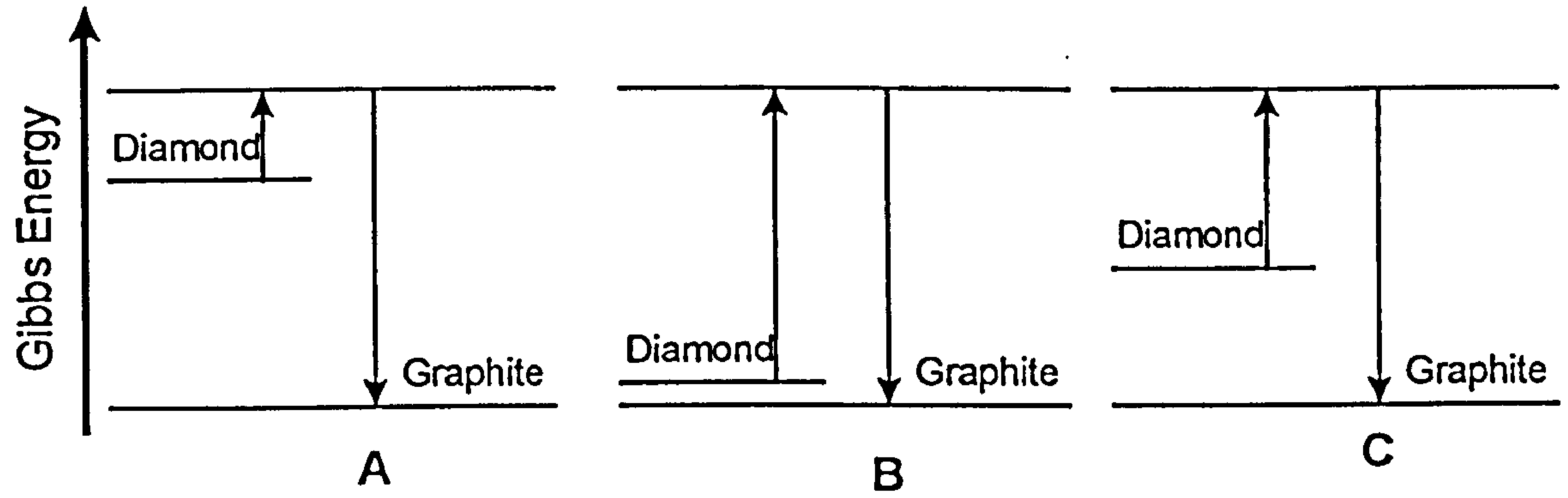
b)In which set of apparatus does energy transferred as heat equal the reaction enthalpy?. Explain your answer as carefully as you can.

Transformation of Diamond to Graphite

The transformation of diamond to graphite is a very slow process which cannot be observed over the duration of human life. The chemical reaction for the transformation process can be given as:

$$C_{(Diamond,s)} \rightarrow C_{(Graphite,s)}$$

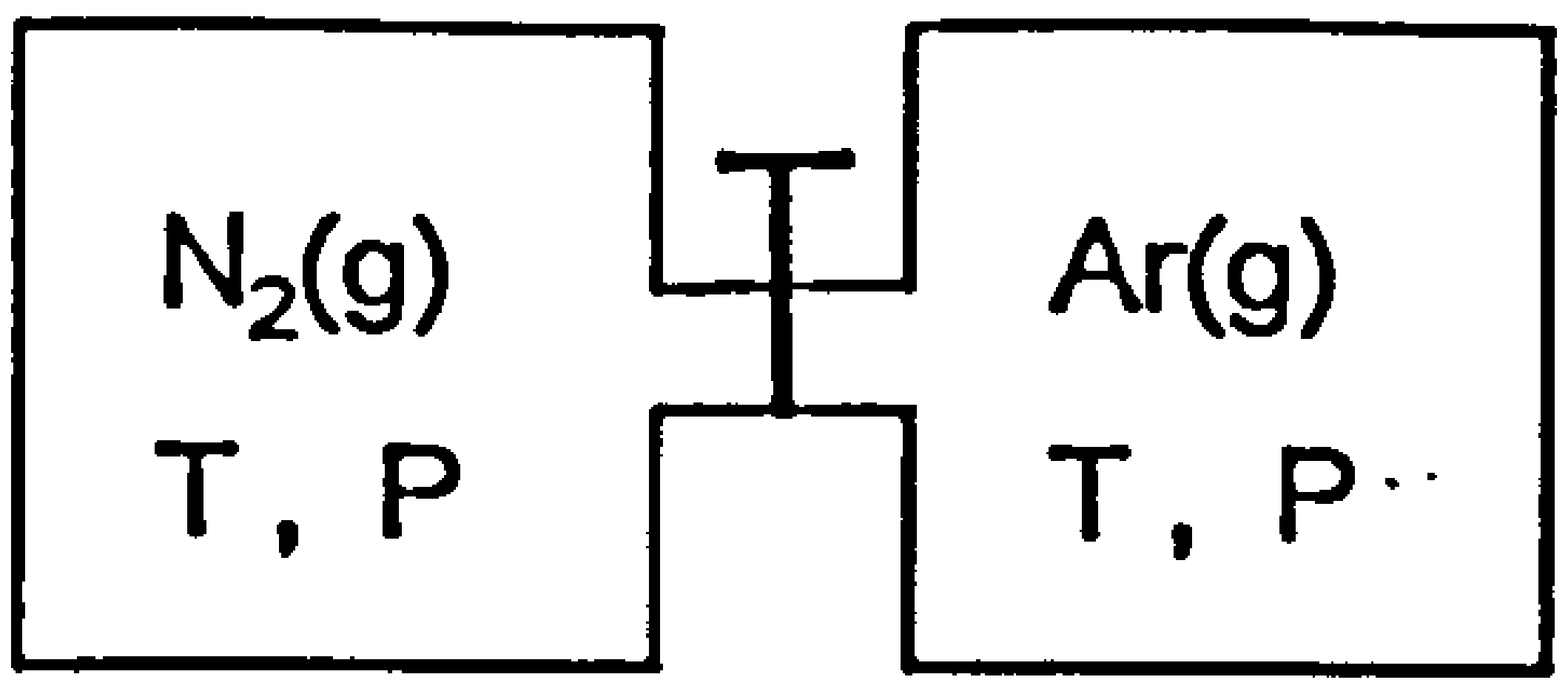
The three diagrams below represent the Gibbs energy changes for the process. Which of these diagrams do you think best represents Gibbs energy change of the transformation of diamond to graphite? Explain your answer as carefully as you can.



Potential Energy

The potential energy of perfect gas molecules is zero. Why?, Explain as carefully as you can.

Mixing of Gases



Imagine that two gases, nitrogen and argon, are placed in equal volume containers which are connected to each other by a tap. Their initial pressures are both P. The tap is opened and the two gases are allowed to mix at constant temperature. After the mixing, the entropy of the gases increases and their final total pressure stays P. Also, argon and nitrogen gases do not react with each other. Using this information:

a) Explain as carefully as you can why entropy increases when the gases mix.

b) Estimate how the enthalpy of the gases changes. Explain your answer as carefully as you can.

c) Estimate how the Gibbs energy of the gases changes. Explain your answer as carefully as you can.

Ice Melting

Consider that there are two identical 1 L glass beakers containing 300 mL of water and 250 g of crushed ice in each. 1 mol NaCl is added to the first beaker and 1 mol KI is added to the second beaker. A certain time later, it was observed that the ice melted quickly in the beaker to which NaCl was added, whereas there was more ice in the beaker to which KI was added.

Using this information, decide which salt absorbs more heat when it dissolves in water. Explain your answer as carefully as you can.

Two Spontaneous Reactions

Two spontaneous reactions are shown below. Their standard Gibbs energies are also given.

1 - $CO(g) + 2\,H_2(g) \rightarrow CH_3OH(l)$ $\Delta_r G^\circ = -2.9 \times 10^4\ \text{J mol}^{-1}$

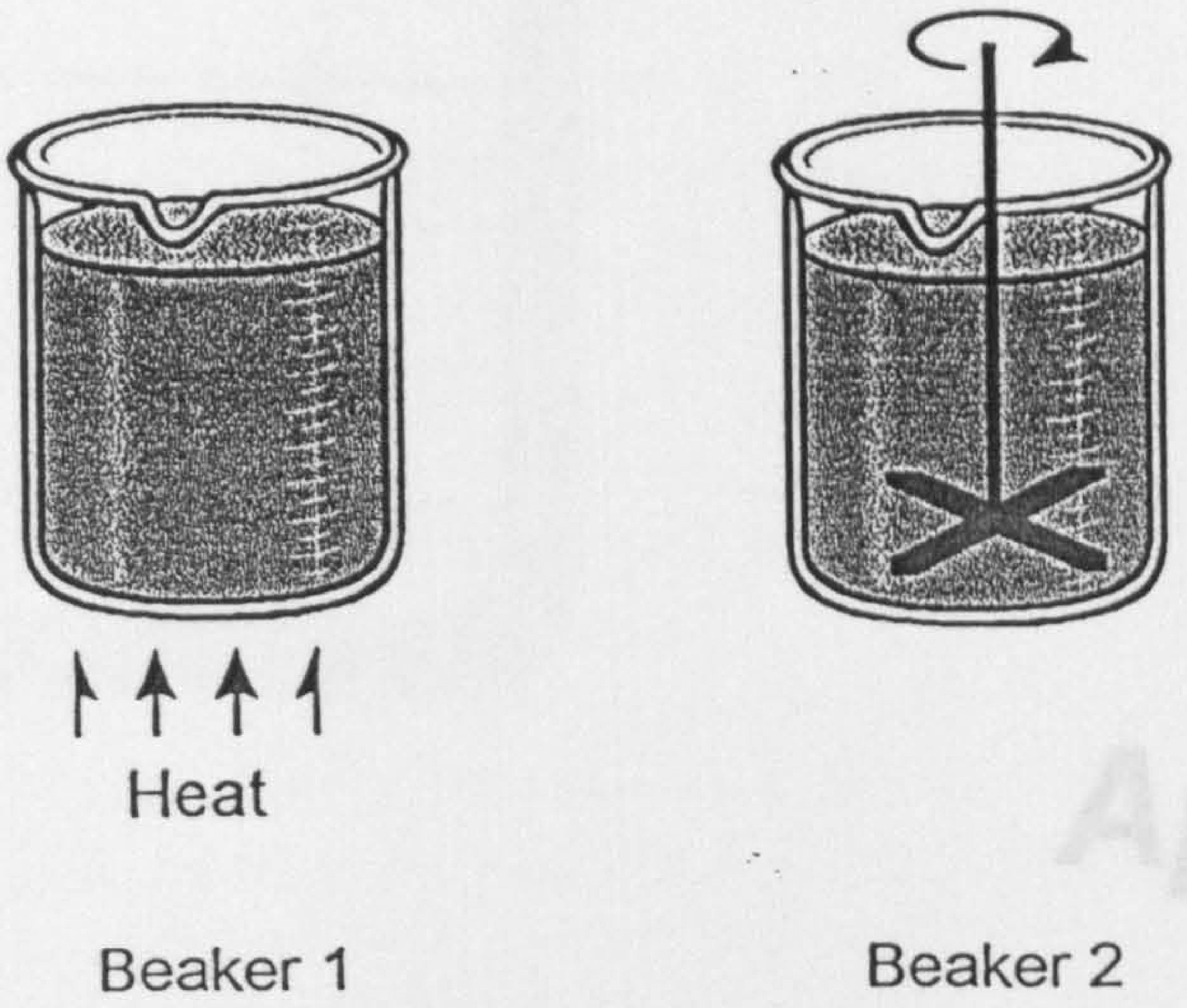
2 - $4\,Fe(s) + 3\,O_2(g) \rightarrow 2\,Fe_2O_3(s)$ $\Delta_r G^\circ = -1.49 \times 10^6\ \text{J mol}^{-1}$

a) Can these data be used to say anything about the relative rates of these reactions? If so why? Explain your answer as carefully as you can.

b) In your opinion, which of the above reactions would most fully go towards completion?

Explain your answer as carefully as you can.

Water



Two identical 1 litre glass beakers each contain 900 cm^3 of water. At the start, both beakers are at room temperature (25 ^{o}C). Later, Beaker 1 is heated by a candle for five minutes while Beaker 2 is stirred vigorously for five minutes.

How will the final internal energies of the two beakers and their contents compare with their initial internal energies? Explain your answer as carefully as you can.

Appendix 5

Post-Test -I (Turkish version)

Adiniz:__________________

Soyadiniz:__________________

Fakulteniz:__________________

Tarih:__________________

ÜNİVERSİTE KİMYA ÖĞRENCİLERİNİN İÇ ENERJİ, ENTALPİ, ENTROPİ VE GİBBS ENERJİSİ KONULARINDAKİ DÜŞÜNCELERİ ÜZERİNE BİR ARAŞTIRMA

(Son -Test - I)

Gereken Süre: Yaklaşık 50 dakika

Başlamadan önce lütfen bir sonraki sayfadaki açıklamaları okuyunuz.

Mustafa SOZBILIR

Egitim Arastirmalari Bolumu
York Universitesi
York YO10 5DD
INGILTERE

Sevgili Öğrenci Arkadaşlar,

Belki sizden niçin böyle bir testi cevaplandırmanız istendiğini düşünebilirsiniz!

Bir doktora öğrencisi olarak, üniversite kimya öğrencilerinin bazı önemli kimya kavramları hakkındaki düşünceleri üzerine bir araştırma yapmaktayım. Bu çalışma yaklaşık üç yıl sürecek. Sizlerin bu testlere vereceği cevaplar, araştırmacılara ve öğretim üyelerine sizlerin bazı termokimya konularını anlamada karşılaştığınız güçlüklerin çözümünde yardımcı olacaktır.

Bu test kimya öğrencilerinin kimyayı ne kadar anladığını saptayabilmek için geliştirilmiştir. Sorular genellikle sizin konu hakkındaki bilgilerinizi yazmaya teşvik eder niteliktedir. Sizden beklenen, her soruyu kendi kimya bilginizi kullanarak dikkatlice cevaplamanızdır. Eğer sorulardan herhangi birine cevap veremezseniz lütfen telaşlanmayınız. Bu bir imtihan değildir. Her soruyu cevaplamak zorunda olmadığınız gibi soruları uzun uzadıya cevaplamanız da beklenmemektedir. Onun için lütfen başkalarından kopya almaya çalışmayınız.

Eğer sorulardan cevaplıyamadıklarınız olursa, onlar üzerinde fazla zaman harcamayınız. Derhal bir sonraki soruya geçiniz.Her soru için yaklaşık 5 dakikalık bir süre size yeterli olacaktır.

Size hatırlatmak istediğim bir başka önemli husus da şudur: Teste sorulan sorulardan hiçbirisine içinizden herhangi birinizin sorması durumunda bile cevap veremeyeceğim. Bu araştırmanın güvenirliği açısından uymam gereken bir kuraldır. Alternatif olarak , ya kendiniz konuyla ilgili araştırma yapabilir ya da hocalarınızla tartışabilirsiniz. Bu konudaki herhangi bir olumsuzluktan dolayı özür dilerim.

Sonuç olarak, sizlerin bu teste vereceği tüm cevaplar kesinlikle gizli tutulacak ve sadece araştırmanın amaçları doğrultusunda kullanılacaktır.

Ayrıca, testi cevaplayan öğrencilerin bir kısmıyla daha fazla bilgi toplayabilmek için mülakat yapmayı planlıyorum. Bu mülakatlar araştırma amacıyla kasete kaydedilecektir. Eğer mülakata katılmak istemiyorsanız lütfen yandaki kutuyu işaretleyiniz ☐.

Kıymetli zamanlarınızı bu testi cevaplamaya ayırdığınız için teşekkür ederim.

Saygılarımla

Mayıs 1999

Mustafa SÖZBİLİR

İki Hayali Reaksiyon

Aşağıda iki hayali kimyasal reaksiyon gösterilmiştir. Bu iki reaksiyon aynı sıcaklıkta gerçekleşmektedir.

Reaksiyon 1	$A + B \rightarrow C + D$	Ekzotermik
Reaksiyon 2	$E + F \rightarrow G + H$	Endotermik

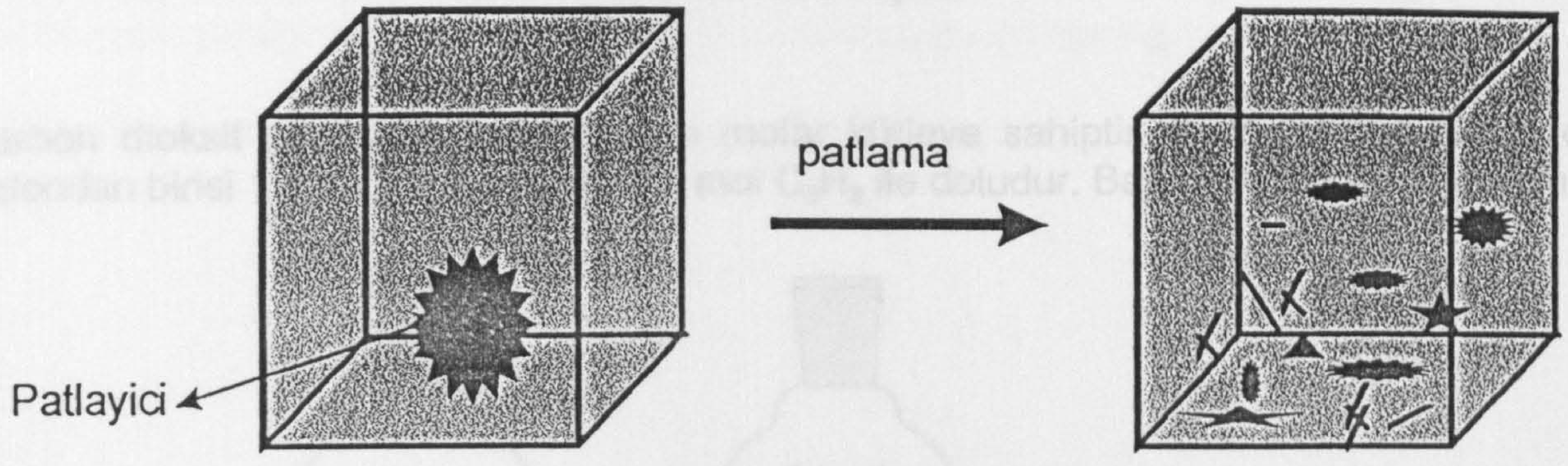
a) Verilen bilgileri kullanarak bu iki reaksiyonun hızları hakkında kıyaslama yapabilirmisiniz? Eğer yapabilirseniz, bu iki reaksiyondan hangisi daha hızlı gerçekleşir?

Lütfen cevabınızı dikkatlice açıklayınız.

b) Bu iki reaksiyonun kendiliğinden gerçekleşebilirlikleri hakkında ne düşünürsünüz?

Lütfen cevabınızı dikkatlice açıklayınız.

Çelik Bir Kapta Patlama



Patlamadan once

Patlamadan sonra

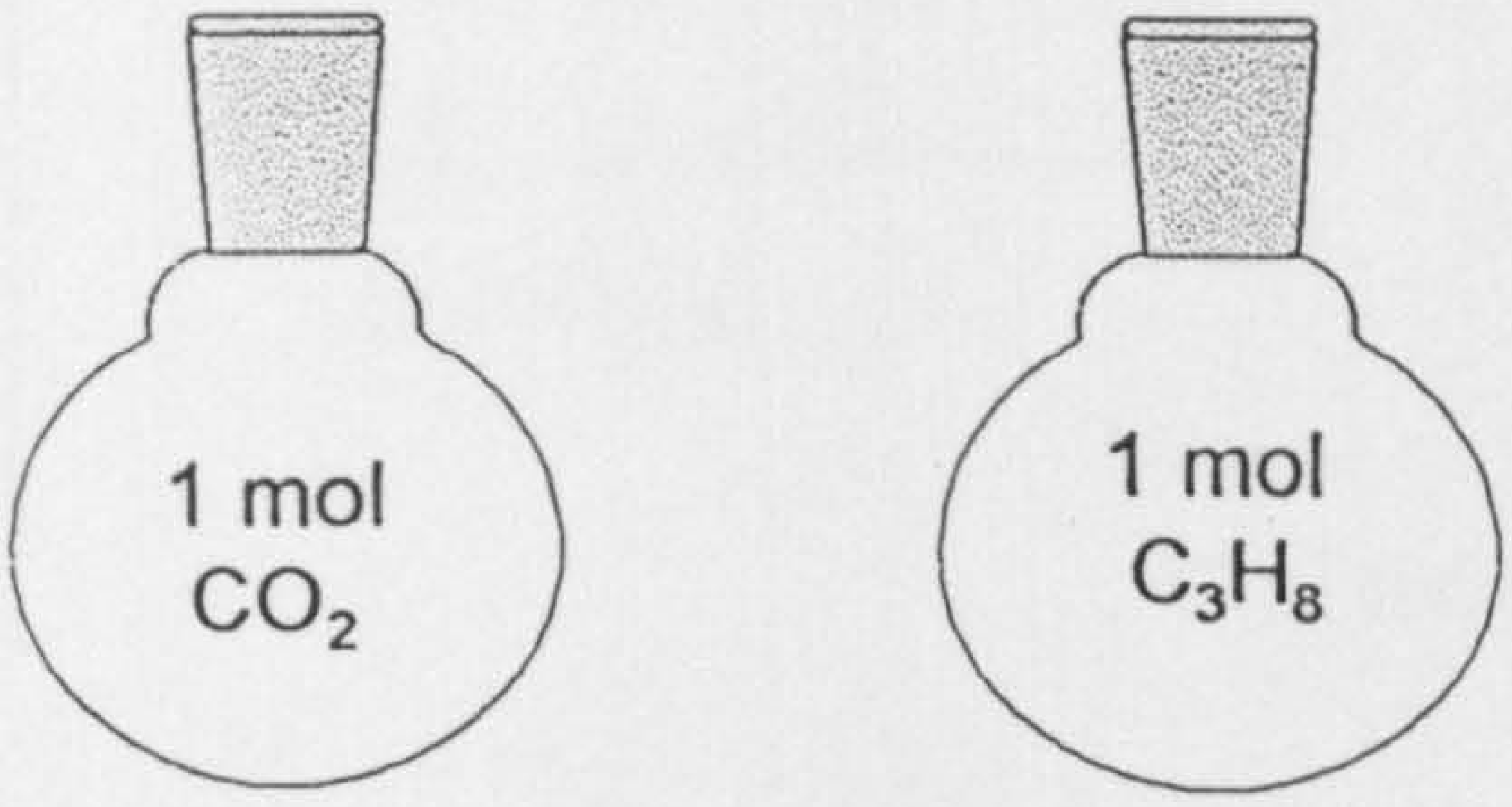
Patlamaya karşı dayanıklı ve çevresinden izole bir çelik kabın içerisine bir patlayıcının yerleştirildiğini ve daha sonrada bu patlayıcının kabın içerisinde patlatıldığını düşünün. Patlamadan sonra, kabın içerisindeki sıcaklık ve basınç artmaktadır. Sistemin bütününün; izole çelik kap, patlamadan sonra oluşan patlayıcının parçaları ve kabın içerisindeki değişik gazlardan oluştuğunu kabul ediniz.

Buna göre, patlamadan önce ve sonra sistemin iç enerjisi hakkında ne düşünürsünüz?

Lütfen cevabınızı dikkatlice açıklayınız.

Karbon Dioksit ve Propan

Karbon dioksit ve propan gazları aynı molar kütleye sahiptir. Aşağıdaki iki özdeş cam balondan birisi 1 mol CO_2 ile diğeride 1 mol C_3H_8 ile doludur. Balonların sıcaklıkları aynıdır.



Bu durumda hangi gazın entropisinin daha fazla olduğunu düşünürsünüz? Lütfen cevabınızı dikkatlice açıklayınız.

Enerji

a) $H_2(g) + ½\,O_2(g) \rightarrow H_2O(g)$ $\Delta_f H^\theta = -242\ kJ\ mol^{-1}$

Yukarıdaki termokimyasal eşitlik, 1 mol H_2 ile1/2 mol O_2 nin 1 mol H_2O oluşturmak üzere reaksiyona girdiğinde 242 kJ enerjinin ısı olarak açığa çıktığını göstermektedir.

Bu reaksiyonda niçin enerji açığa çıktığını dikkatlice açıklayınız.

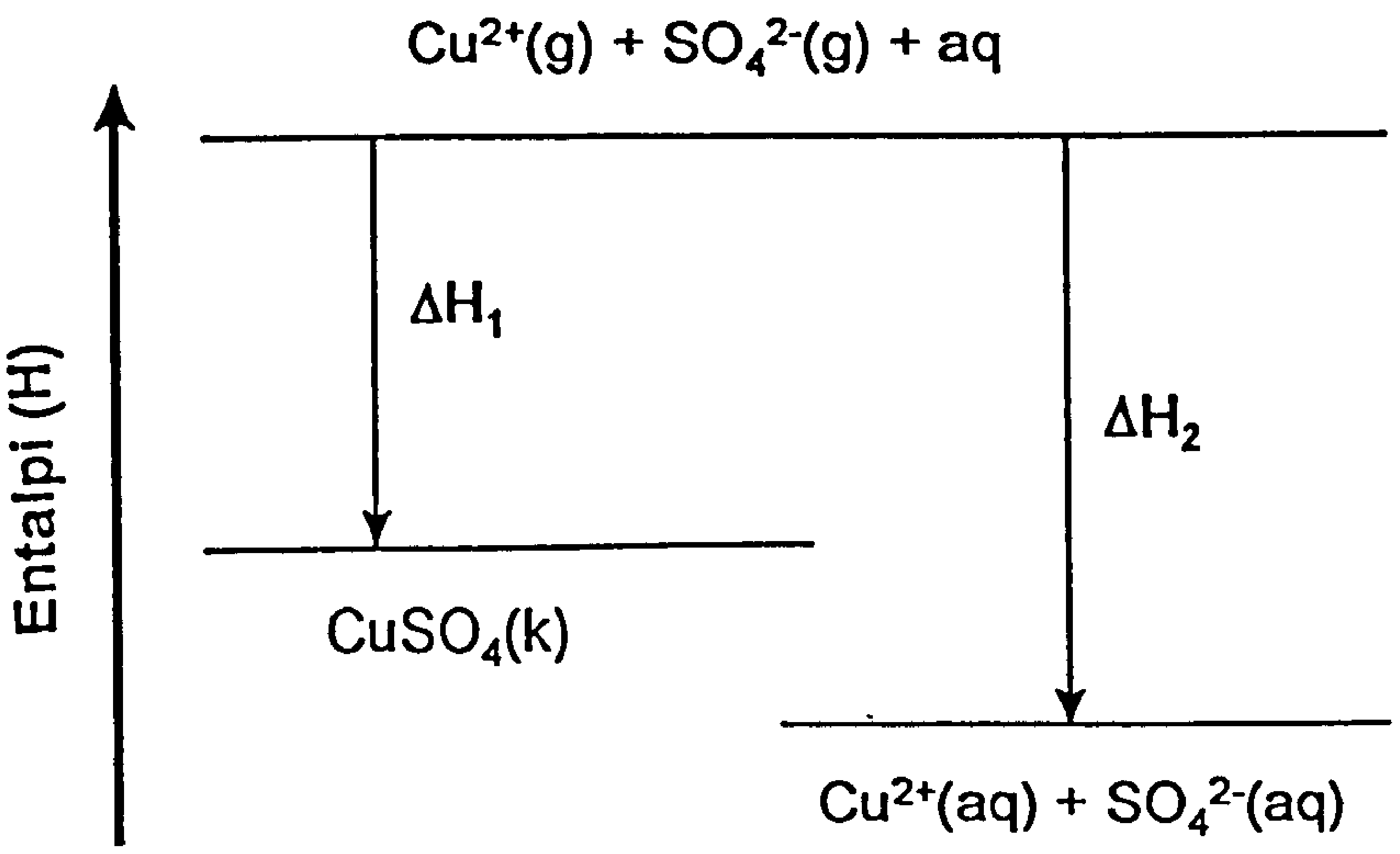
b) $N_2(g) + 2\,O_2(g) \rightarrow 2\,NO_2(g)$ $\Delta_f H^\theta = 68\ kJ\ mol^{-1}$

Yukarıdaki termokimyasal eşitlik 1 mol N_2 ile 2 mol O_2 2 mol NO_2 oluşturmak üzere sabit basınçta reaksiyona girdiğinde ısı aldığını göstermektedir.

Bu reaksiyonda niçin ısının absorplandığını dikkatlice açıklayınız.

Bakır(II) Sülfat

Aşağıda susuz bakır (II) sülfatın çözünürlüğüne ait enerji diagramı gösterilmiştir.



a) Diagram üzerinde ΔH_1 ve ΔH_2 olarak gösterilen entalpi değişimlerinin adlarını verilen boşluğa yazınız.

ΔH_1.., ΔH_2..

b) Yukarıdaki diagram üzerinde $CuSO_4$(k)'ün çözünürlüğüne ait entalpi değişimini ($\Delta_{\text{çöz}} H$) bir ok çizerek gösteriniz.

c) Susuz bakır(II) sülfat suda çözündüğünde suyun sıcaklığının artmasını mı yoksa azalmasını mı beklersiniz? Lütfen cevabınızı dikkatlice açıklayınız.

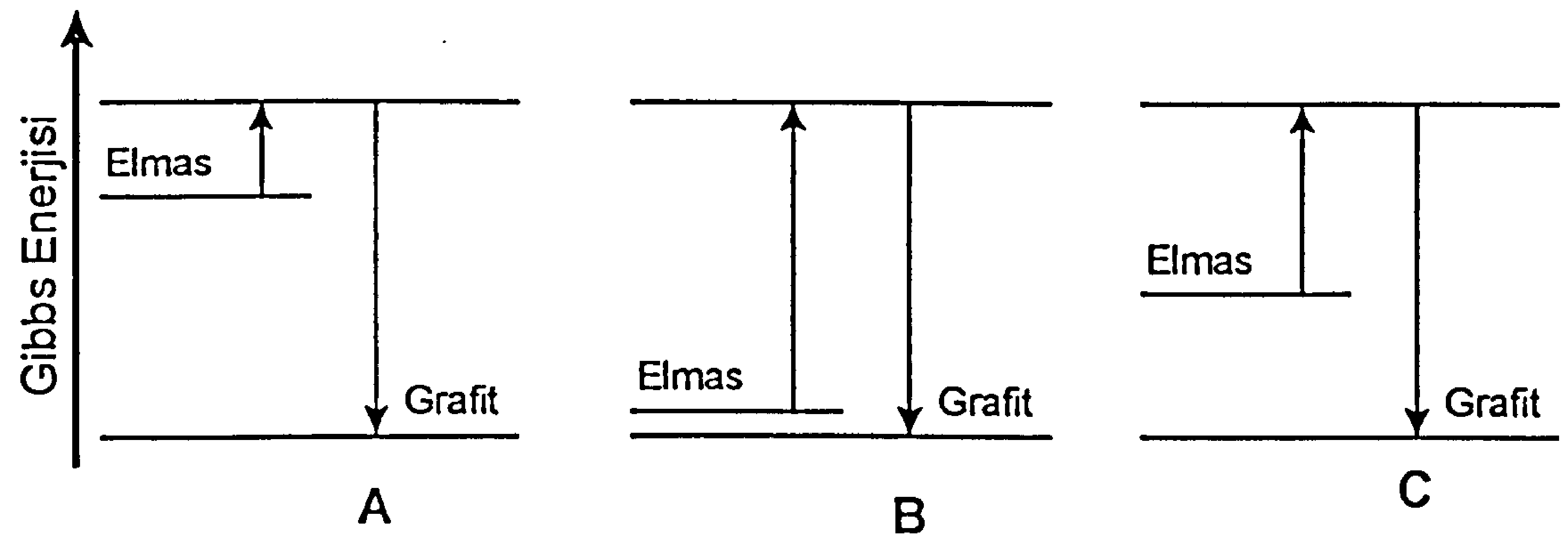
Elmasın Grafite Dönüşümü

Elmasın grafite dönüşümü bir insan ömrünün gözlemeye yetmeyeceği kadar yavaş yürüyen bir prosestir. Dönüşüm reaksiyonu aşağıdaki gibi verilebilir.

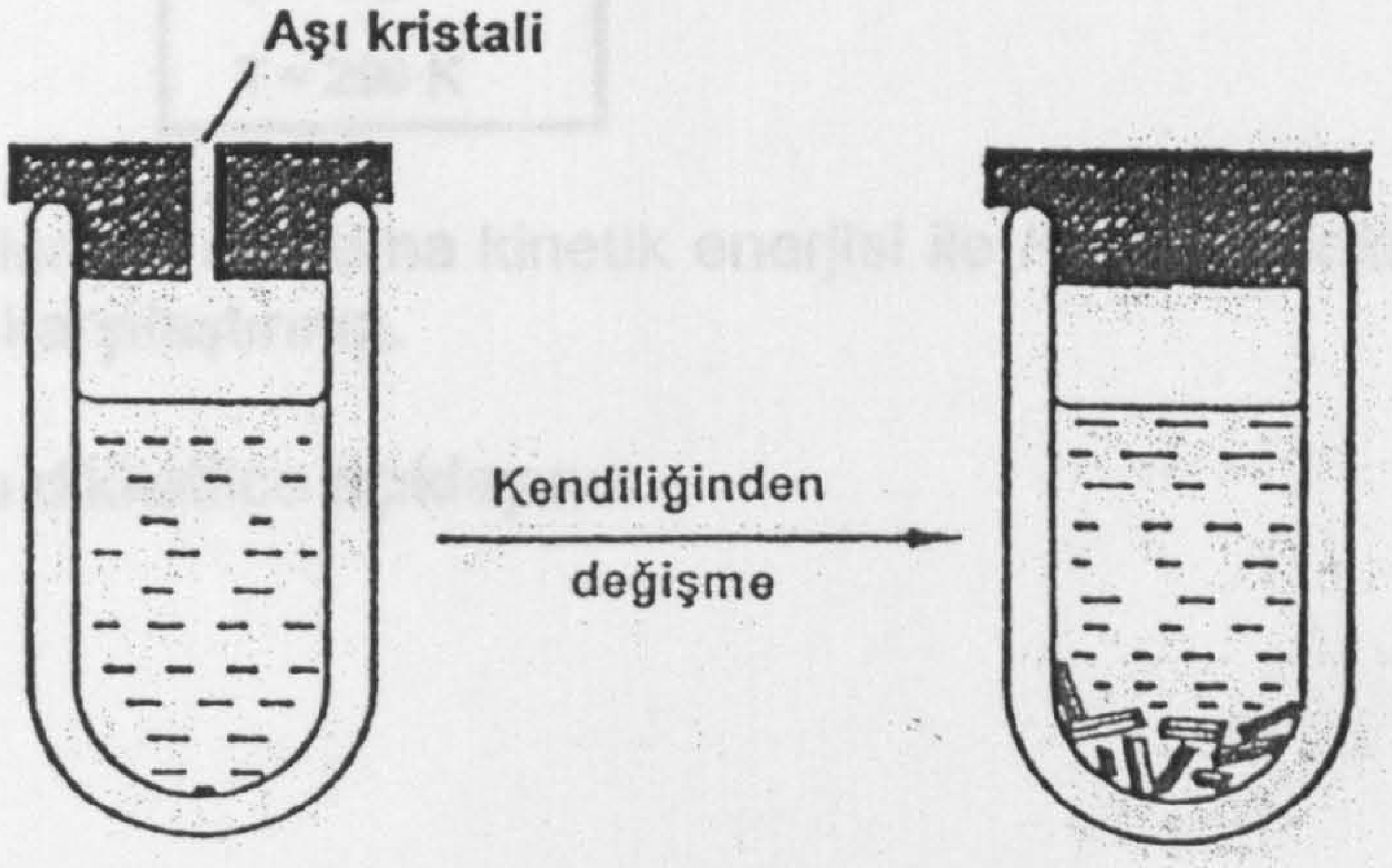
$$C_{(Elmas,k)} \rightarrow C_{(Grafit,k)}$$

Aşağıdaki üç diagram prosese ait Gibbs enerji değişimini göstermektedir. Size göre bu üç diagramdan hangisi elmasın grafite dönüşüm prosesini en iyi şekilde gösterir?

Lütfen cevabınızı dikkatlice açıklayınız.



Kendiliğinden Gerçekleşen Değişme



Aşırı doygun ve sıcak bir sodyum tiyosülfat çözeltisi soğumaya bırakılıyor. Soğuma sırasında eğer çözeltide kirliliğe sebep olacak herhangi bir materyal yoksa süper soğuma (*herhangi bir maddenin normal donma noktasının altındaki bir sıcaklıkta donmadan kalması*) gerçekleşebilir. Daha sonra, süper soğumuş çözelti termal olarak izole bir kaba yerleştiriliyor. Çözeltiye bir tane aşı kristali (*sodyum tiyosülfat kristali*) atılıyor ve çözeltide kendiliğinden kristallenme olduğu gözleniyor.

Kristallenme gerçekleştikten sonra sistemin entropisinde nasıl bir değişme olacağını düşünürsünüz?

Lütfen cevabınızı dikkatlice açıklayınız.

Helyum ve Karbon Dioksit

a)

He ile dolu
$n = 1$ mol
$V = 1$ L
$T = 298$ K

CO_2 ile dolu
$n = 1$ mol
$V = 1$ L
$T = 298$ K

Yandaki iki kap aynı sıcaklıkta 1 mol He ve 1 mol CO_2 içermektedir.

Helyum moleküllerinin ortalama kinetik enerjisi ile *Karbon Dioksit* moleküllerinin ortalama kinetik enerjisini karşılaştırınız.

Lütfen cevabınızı dikkatlice açıklayınız.

b)

He ile dolu
$n = 1$ mol
$V = 1$ L
$T = 298$ K

A

He ile dolu
$n = 1$ mol
$V = 0{,}5$ L
$T = 298$ K

B

Yandaki iki kap aynı sıcaklıkta birer mol He içermektedir.

Her iki kaptaki *Helyum* moleküllerinin ortalama kinetik enerjileri hakkında ne söyleyebilirsiniz?

Lütfen cevabınızı dikkatlice açıklayınız.

Appendix 6

Post-Test -II (Turkish version)

Adiniz:__________________

Soyadiniz:________________

Fakulteniz:________________

Tarih:___________________

ÜNİVERSİTE KİMYA ÖĞRENCİLERİNİN İÇ ENERJİ, ENTALPİ, ENTROPİ VE GİBBS ENERJİSİ KONULARINDAKİ DÜŞÜNCELERİ ÜZERİNE BİR ARAŞTIRMA

(Son -Test - II)

Gereken Süre: Yaklaşık 50 dakika

Başlamadan önce lütfen bir sonraki sayfadaki açıklamaları okuyunuz.

Mustafa SOZBILIR

Egitim Arastirmalari Bolumu
York Universitesi
York YO10 5DD
INGILTERE

Sevgili Öğrenci Arkadaşlar,

Belki sizden niçin böyle bir testi cevaplandırmanız istendiğini düşünebilirsiniz!

Bir doktora öğrencisi olarak, üniversite kimya öğrencilerinin bazı önemli kimya kavramları hakkındaki düşünceleri üzerine bir araştırma yapmaktayım. Bu çalışma yaklaşık üç yıl sürecek. Sizlerin bu testlere vereceği cevaplar, araştırmacılara ve öğretim üyelerine sizlerin bazı termokimya konularını anlamada karşılaştığınız güçlüklerin çözümünde yardımcı olacaktır.

Bu test kimya öğrencilerinin kimyayı ne kadar anladığını saptayabilmek için geliştirilmiştir. Sorular genellikle sizin konu hakkındaki bilgilerinizi yazmaya teşvik eder niteliktedir. Sizden beklenen, her soruyu kendi kimya bilginizi kullanarak dikkatlice cevaplamanızdır. Eğer sorulardan herhangi birine cevap veremezseniz lütfen telaşlanmayınız. Bu bir imtihan değildir. Her soruyu cevaplamak zorunda olmadığınız gibi soruları uzun uzadıya cevaplamanız da beklenmemektedir. Onun için lütfen başkalarından kopya almaya çalışmayınız.

Eğer sorulardan cevaplıyamadıklarınız olursa, onlar üzerinde fazla zaman harcamayınız. Derhal bir sonraki soruya geçiniz.Her soru için yaklaşık 5 dakikalık bir süre size yeterli olacaktır.

Size hatırlatmak istediğim bir başka önemli husus da şudur: Teste sorulan sorulardan hiçbirisine içinizden herhangi birinizin sorması durumunda bile cevap veremeyeceğim. Bu araştırmanın güvenirliği açısından uymam gereken bir kuraldır. Alternatif olarak , ya kendiniz konuyla ilgili araştırma yapabilir ya da hocalarınızla tartışabilirsiniz. Bu konudaki herhangi bir olumsuzluktan dolayı özür dilerim.

Sonuç olarak, sizlerin bu teste vereceği tüm cevaplar kesinlikle gizli tutulacak ve sadece araştırmanın amaçları doğrultusunda kullanılacaktır.

Ayrıca, testi cevaplayan öğrencilerin bir kısmıyla daha fazla bilgi toplayabilmek için mülakat yapmayı planlıyorum. Bu mülakatlar araştırma amacıyla kasete kaydedilecektir. Eğer mülakata katılmak istemiyorsanız lütfen yandaki kutuyu işaretleyiniz ☐.

Kıymetli zamanlarınızı bu testi cevaplamaya ayırdığınız için teşekkür ederim.

Saygılarımla

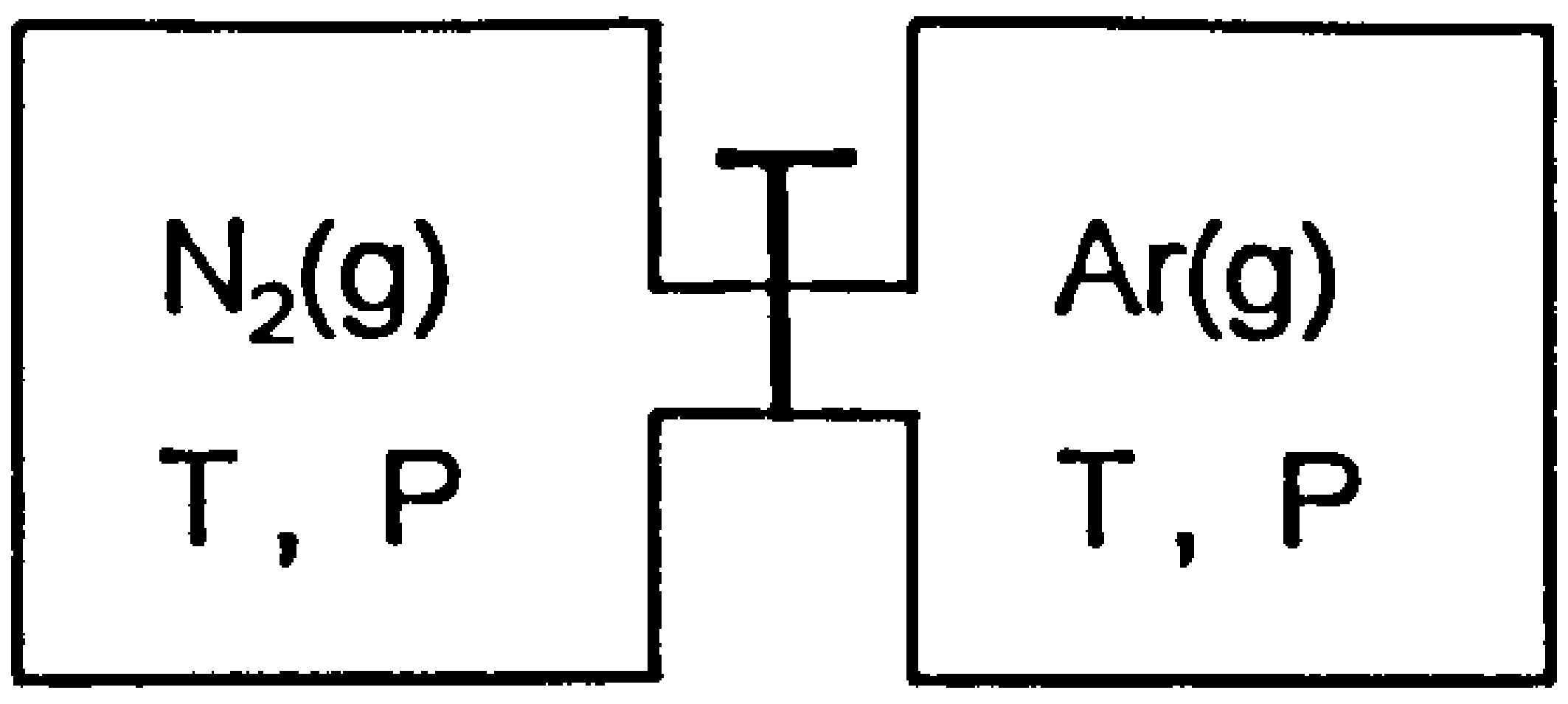
Mayıs 1999

Mustafa SÖZBİLİR

Potansiyel Enerji

İdeal gaz moleküllerinin potansiyel enejileri sıfır olarak kabul edilir. Niçin? Lütfen cevabınızı dikkatlice açıklayınız.

Gazların Karışması



Yukarıda gösterilen her iki kabın hacimleri aynıdır ve iki kap birbirlerine bir muslukla bağlanmışlardır. Kaplardan birinde azot, digerinde de argon gazı vardır. Gazların başlangıç basınçları P'dir. Sabit sıcaklıkta musluk açılarak gazların birbiriyle karışması sağlanmıştır. Gazların karışmasından sonra entropileri artmakta, toplam basınç ise P olarak kalmaktadır. (Argon ve azot gazları birbirleriyle reaksiyon vermezler.)

Bu bilgileri kullanarak aşağıdaki soruları cevaplandırınız.

a) Gazlar karıstıklarında entropi neden artmaktadır? Lütfen cevabınızı dikkatlice açıklayınız.

b) Gazların karışması sırasında entalpi değişimi nasıl olur?
Lütfen cevabınızı dikkatlice açıklayınız.

c) Gazların karışması sırasında Gibbs enerji değişimi nasıl olur?
Lütfen cevabınızı dikkatlice açıklayınız.

Buzun Erimesi

İki tane özdeş 1 L'lik cam beherlerde 300 mL su ve 250 g parçalanmış buz vardır. Birinci behere 1 mol NaCl, ikincisine de 1 mol KI ilave edilmiştir. Belli bir süre sonra NaCl ilave edilen beherdeki buzların çabucak erirken KI eklenen beherde buz parçacıklarının olduğu görülmüştür.

Bu bilgileri kullanarak, hangi tuzun suda çözünmesi sırasında daha ısı absorplandığına karar veriniz. Lütfen cevabınızı dikkatlice açıklayınız.

Kendiliğinden Gerçekleşen İki Reaksiyon

Aşağıda iki tane kendiliğinden gerçekleşen reaksiyon verilmiştir. Bu iki reaksiyonun standart reaksiyon Gibbs serbest enerjileri verildigi gibidir.

1 - $CO(g) + 2H_2(g) \rightarrow CH_3OH(s)$ $\Delta_r G^\ominus = -2.9 \times 10^4\ J\ mol^{-1}$

2 - $4Fe(k) + 3O_2(g) \rightarrow 2Fe_2O_3(k)$ $\Delta_r G^\ominus = -1.49 \times 10^6\ J\ mol^{-1}$

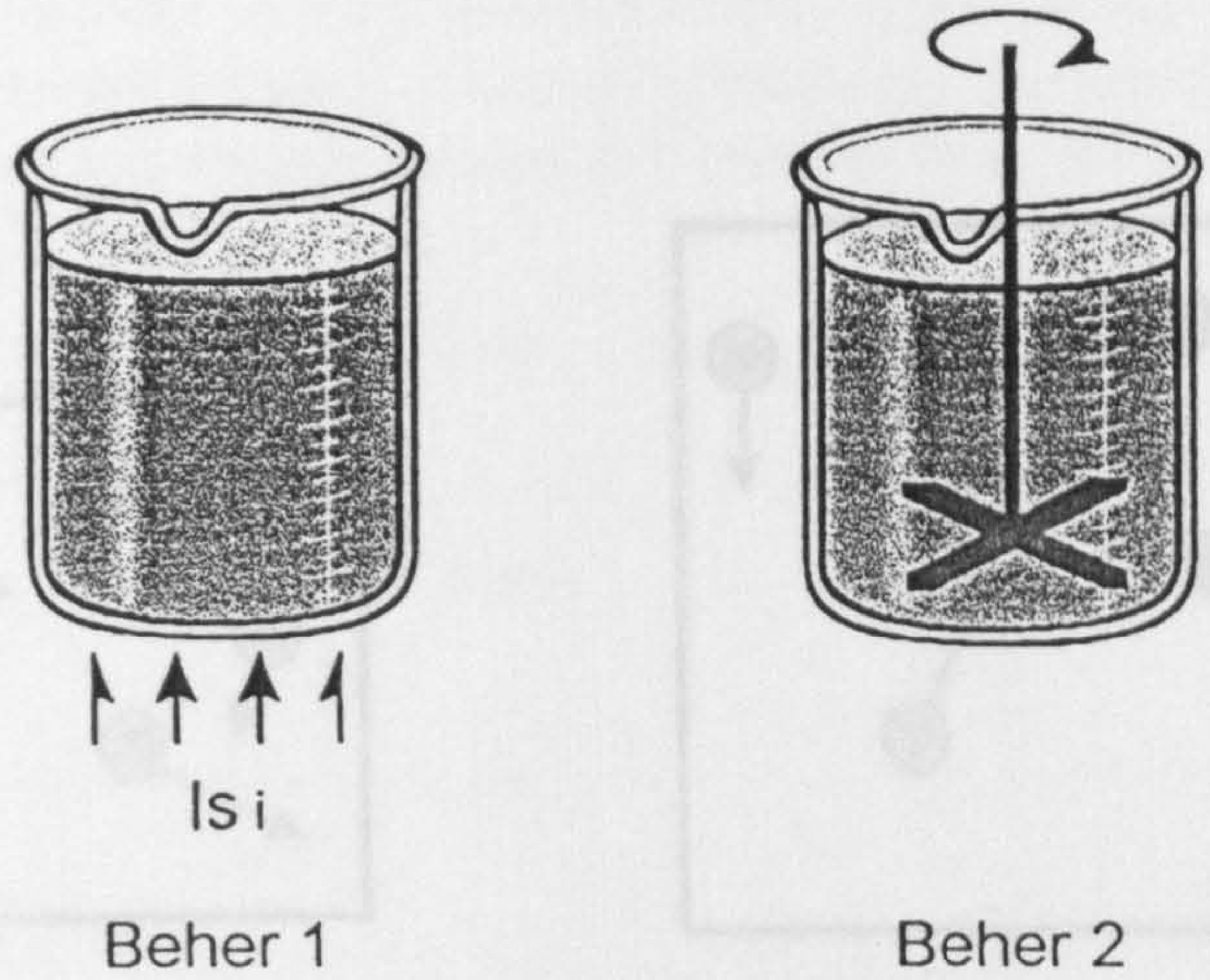
a) Bu verileri kullanarak yukarıdaki iki reaksiyonun hızları hakkında bir kıyaslama yapabilirmisiniz? Eğer kıyaslama yapabilirseniz reaksiyonların hızları nasıl olur?

Lütfen cevabınızı dikkatlice açıklayınız.

b) Sizce, yukarıdaki iki reaksiyondan hangisinin tam olarak tamamlanmaya doğru gitme eğilimi daha fazladır?

Lütfen cevabınızı dikkatlice açıklayınız.

Su

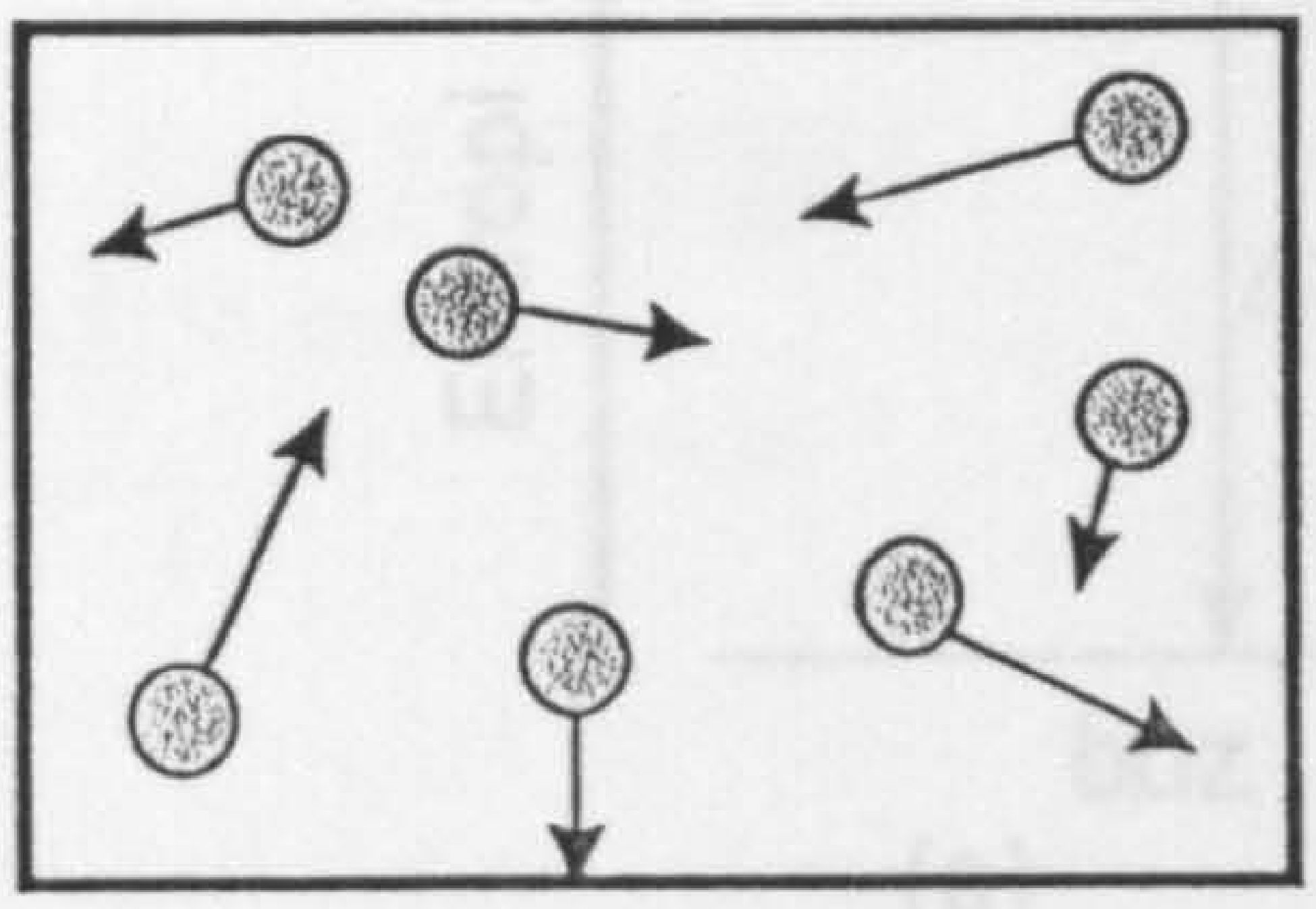


İki özdeş 1 L'lik cam beherlerin herbirinde 900 cm^3 su vardır. Beherlerin her ikiside aynı ortamda olup, başlangıç sıcaklıkları 25 ^{o}C dir. Daha sonra birinci beher bir ısıtıcı yardımıyla beş dakika ısıtılırken, ikinci beher bir karıştırıcı yardımıyla hızlı bir şekilde beş dakika süreyle karıştırılmaktadır.

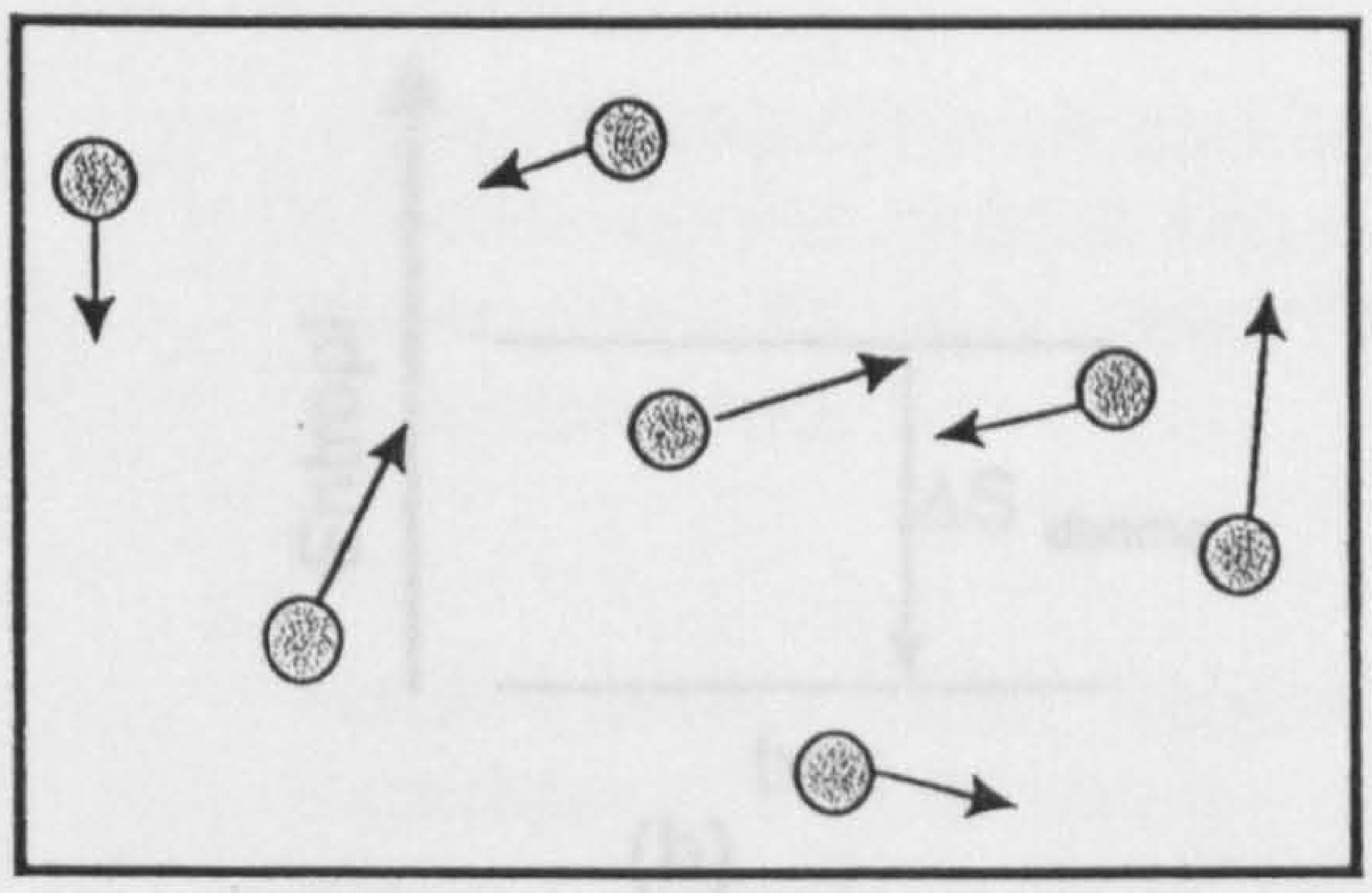
Her iki beher ve içeriklerinin son hallerindeki iç enerjileri onların başlangıç hallerindeki iç enejilerine kıyasla nasıl değişir?

Lütfen cevabınızı dikkatlice açıklayınız.

Mükemmel Gaz



A



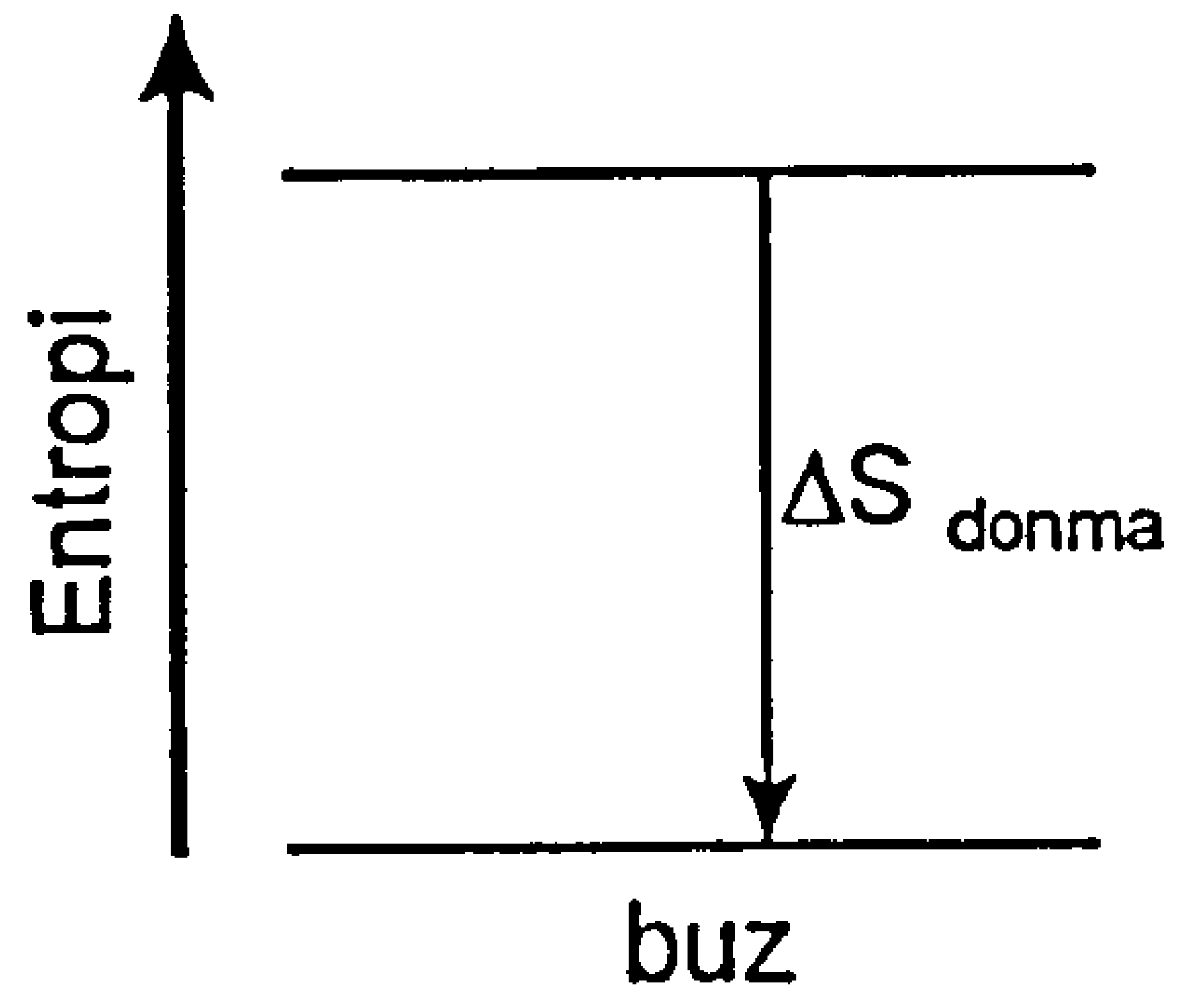
B

Yukarıdaki (A) kabında belli bir sıcaklıkta bir mükemmel gaz vardır. Kabın hacmi izotermal olarak (yani sıcaklığı sabit tutularak) iki katına çıkarılıyor (B).

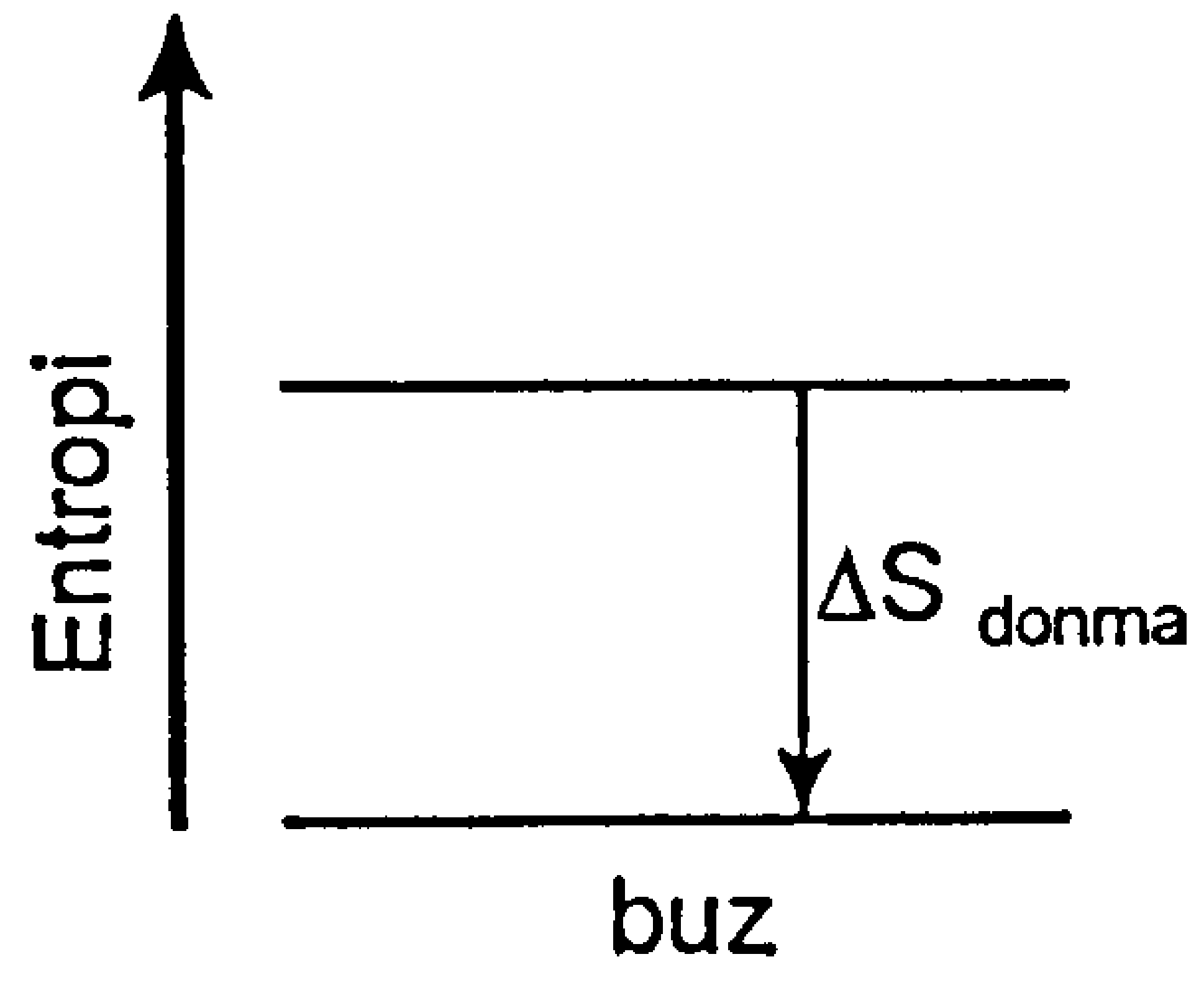
Genleşmeden sonra gazın iç enerjisi hakkında ne düşünürsünüz? Lütfen cevabınızı dikkatlice açıklayınız.

Deniz Suyu

Deniz suyu değişik türlerde çözünmüş mineraller içerir. Bu yüzden de saf suya göre daha düşük sıcaklıklarda donar. Aynı miktarda deniz suyu ve saf su donduklarında çevreye aynı miktarda enerji salıverilir (yani donma entalpileri aynıdır). Aşağıdaki iki diagram deniz suyunun ve saf suyun donması sırasındaki entropi değişimini göstermektedir.



(a)



(b)

a) Yukarıdaki grafiklerden hangisinin deniz suyunun donmasına eşlik eden entropi değişimini gösterdiğine karar veriniz ve cevabınızı dikkatlice açıklayınız.

b) Saf suyun 0 °C ve 1 bar'da donmasına eşlik eden entropi değişimi

$$H_2O(s) \rightarrow H_2O(k) \qquad \Delta S = -22,0\ J\ K^{-1}\ mol^{-1}\text{'dir.}$$

Buna göre 0 °C ve 1 bar'da, deniz suyu donduğu zaman çevrenin entropisinde meydana gelecek değişmenin büyüklüğü ile saf su donduğu zaman çevrenin entropisinde meydana gelen değişmenin büyüklüklerini kıyaslayınız.

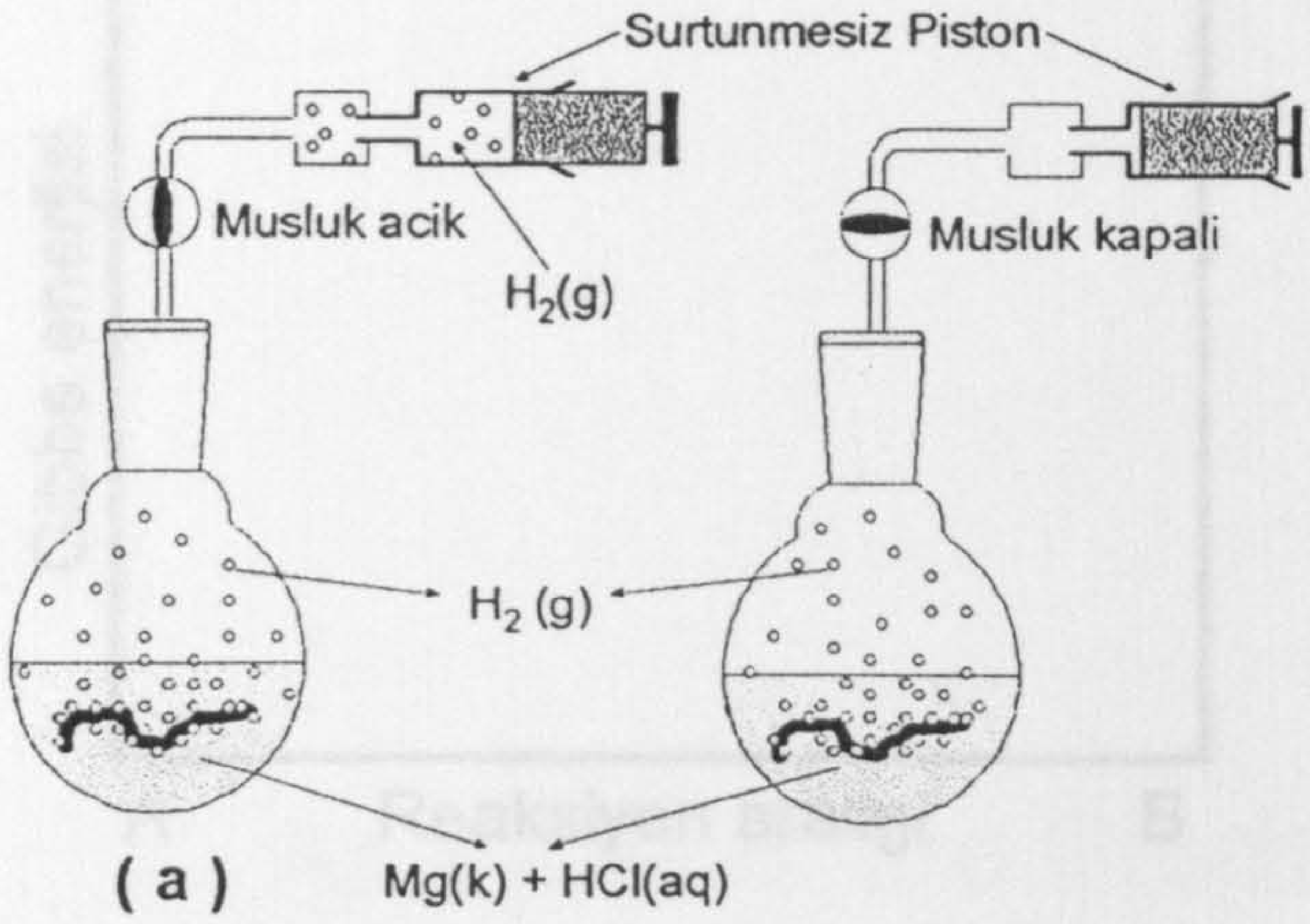
Lütfen cevabınızı dikkatlice açıklayınız.

Mağnezyum

Aşağıdaki her iki deney düzeneğinde de;

$$Mg(k) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta_rH = -\,463\ kJ\ mol^{-1}$$

reaksiyonu gerçekleşmektedir.



a düzeneğinde musluk açık iken,

b düzeneğinde musluk kapalıdır. Her iki düzenekte de aynı miktarda reaktant kullanılmaktadır.

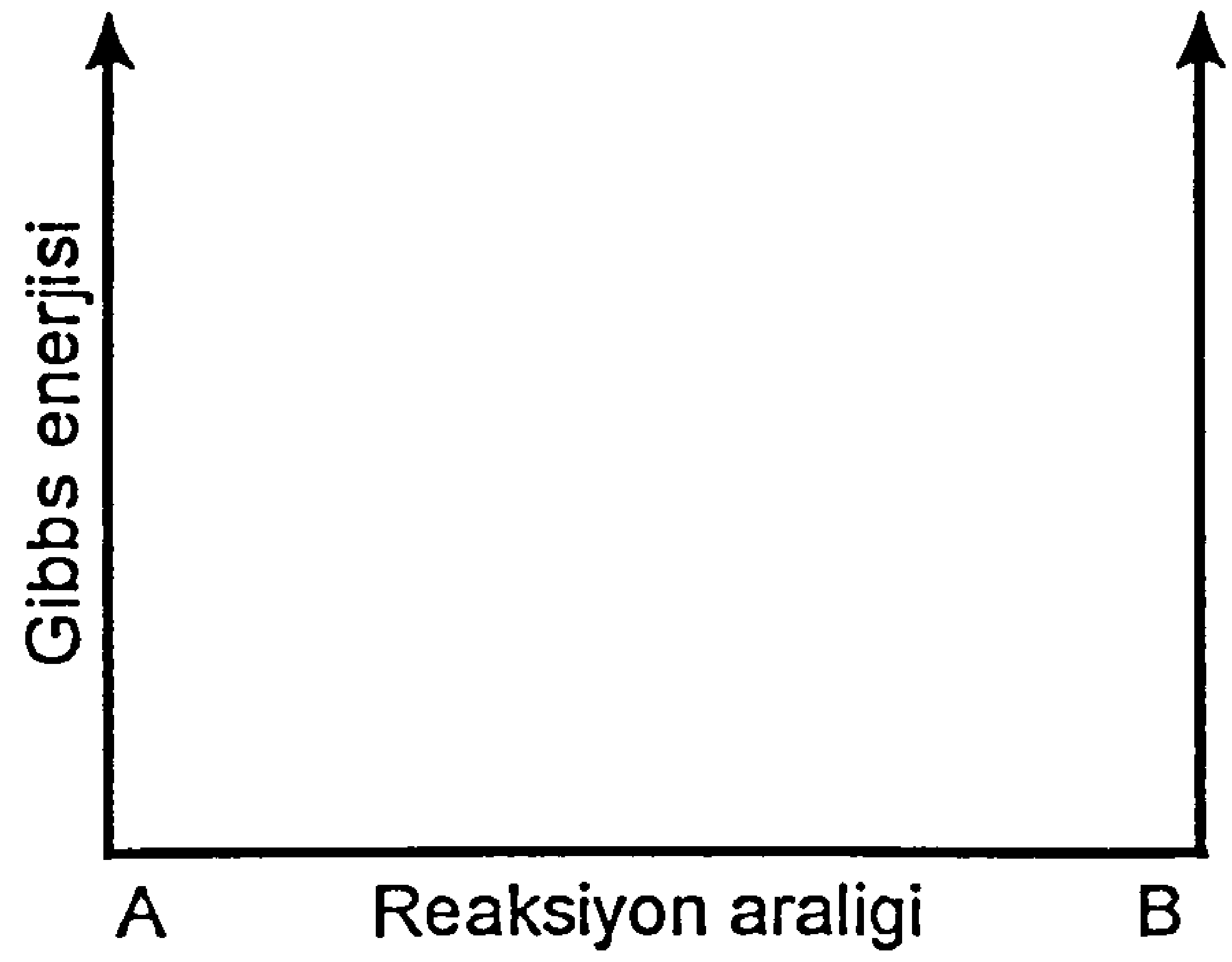
Reaksiyondan sonra sistemin başlangıç sıcaklığına soğutulduğunu ve çevreye yayılan ısının hepsini ölçebildiğinizi düşünün.Buna göre;

a) Hangi deney düzeneğinde çevreye daha fazla ısı yayılır? Lütfen cevabınızı dikkatlice açıklayınız.

b) Hangi deney düzeneğinde çevreye yayılan ısı reaksiyon entalpisine eşittir?

Lütfen cevabınızı dikkatlice açıklayınız.

Gibbs Enerjisi



A → B şeklindeki bir reaksiyonunun reaksiyon ilerledikçe , reaksiyon aralığına karşılık reaksiyon Gibbs enerjisindeki değişimin nasıl olacağını yanda verilen şekil üzerinde grafik çizerek gösteriniz.

Çizdiğiniz grafiği lütfen dikkatlice yorumlayınız.

Appendix 7

Analysis of the Students' Responses to the Trial Questions

(A comprehensive discussion of the pilot study results)

Analysis of the Students' Responses to the Trial Questions

This section examines the students' responses to the trial questions. A few students' responses are quoted under each heading in order to keep this section to a practical length. Each quoted response is followed by a student reference such as P_1/B/S_1. Here, P_1 indicates that question from Pilot 1 (Appendix 1), **B** refers to the first letter of the city where the participating university is established, and S_1 indicates the student number, in this case student number 1. The letter '**E**' refers to the capital letter of the other city where the second participating university is established. No code is used for the questions because each question has a name and also analysis is made question by question.

The coding scheme

The coding scheme used to analyse the students' responses for trial questions was adapted from Abraham *et* al's (1992) study. The same coding scheme was used for both test packages (Appendix 1 and 2). The coding scheme is shown below.

Table1. Coding Scheme

Coding Scheme		
Code	***Degree of Understanding***	***Criteria for Scoring***
1	No response	Blank I don't know I don't understand
2	No understanding	Repeats question Irrelevant or unclear responses
3	No understanding with specific misunderstanding	Response that include irrelevant or unclear responses and illogical or incorrect information
4	Partial understanding with specific misunderstanding	Responses that show understanding of the concept but also make statements which demonstrate a misunderstanding
5	Partial understanding	Responses that include at least one of the components of the validated response, but not all the components
6	Sound understanding	Responses that include all components of the validated response

Analysis of the Results

Analysis is made on a question by question basis and the responses for each question are categorised and tabulated. In the tables the number of the responses and their corresponding percentages are shown. The analysis was done in the same question order as given in the appendices. In the next part of the section the results are discussed.

Copper (II) Sulphate (In Appendix 1)

Table 1 Students' responses to **Copper (II) Sulphate** question in Appendix 1

Response Code	Number of responses			Percentage of responses (%)		
	a	b	c	a	b	c
1	1	1	3	5	5	13
2	4	7	2	18	32	9
3	-	-	7	-	-	32
4	4	-	1	18	-	5
5	7	8	2	32	36	9
6	6	6	7	27	27	32
Total	22	22	22	100	100	100

As can be seen from Table1, almost half of the students, in total, partially understood or sound understood the chemical idea tested in this question. But, there were many responses that show misunderstandings or no understanding at all, especially in the first part of the question "choice a" where a considerable proportion of the students confused 'enthalpy of formation" with "ionization enthalpy" and "hydration enthalpy". In addition, 32% of the students were not able to draw an arrow on the energy level diagram to indicate the enthalpy change of solution. Nearly half of the sample showed either no understanding or a poor understanding of interpreting the energy level diagram. Many responses to "choice c" indicate that students have misunderstandings such as:

> *I will expect a decrease of the temperature of water. Because solubility is an exothermic process. So, temperature of water will decrease (P$_4$/E/S$_7$).*
>
> *I will expect a decrease of temperature of water. Because, the energy needed to soluble of matter will be supplied from the surroundings. Medium temperature will*

> *drop (P_1/E/S_{13}).*
>
> *Solubility is an endothermic process. So, while the copper (II) sulphate soluble the process gets heat from the water and thus causes to cool down the water (P_1/E/S_{15}).*
>
> *Decreases, because energy is needed for ionization of a solid (P_1/B/S_1).*

The quotations show that some students are not able to differentiate between how the temperature of surroundings will change according to the exothermic and endothermic reactions. Also some of them did not consider the energy level diagram and just interpreted the process as solubility only.

Copper (II) Sulphate (In Appendix 2)

Table 2 Students' responses to **Copper (II) Sulphate** question in Appendix 2

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	3	6	15	30
2	5	10	25	50
3	1	1	5	5
4	-	2	-	10
5	11	1	55	5
6	-	-	-	-
Total	20	20	100	100

This question was the open ended version of the same question with the question under the same name in Appendix 1. Students made more mistakes than the same question in the first package. Table 2 shows that no response demonstrated a sound understanding and also slightly more number of the respondents did not respond to the question.

Most of the responses demonstrated that the names of the changes for lattice enthalpy and hydration enthalpy were recalled only very poorly. Students in general confused lattice enthalpy with sublimation enthalpy and interestingly hydration enthalpy with condensation enthalpy and freezing enthalpy. The same difficulty was observed for drawing an arrow to indicate enthalpy change of solution on the diagram. Some students did not pay attention to the direction of the arrows which are crucial to determine the process.

Responses to the second part of the question were short and demonstrated little understanding of the chemical phenomena and no further misunderstandings were determined. The same difficulty was observed in understanding whether the reaction is exothermic or endothermic from the energy level diagram as quoted below:

> *I understand that reaction is endothermic from the energy diagram (P_2/B/S_{10}).*
> *The diagram shows the enthalpy change during the solubility of the dehydrated $CuSO_4$. It shows the decrease of enthalpy (P_2/B/S_{10}).*

Helium and Carbon Dioxide (In Appendix 1)

Table 3 Students' responses to Helium and Carbon Dioxide question in Appendix 1

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	-	-	-	-
2	4	3	18	14
3	9	10	40	45
4	1	-	5	-
5	1	2	5	9
6	7	7	32	32
Total	22	22	100	100

This question revealed that nearly 60% of the students had either no understanding or misunderstandings about kinetic energy and around 32% of them showed a sound understanding. The remained showed only partial understanding.

In the responses, they generally confused the kinetic energy with the rate of the gas molecules and molecular mass, because a comparison was made between the molecular mass and velocity. The question generated many responses illustrating this:

> *He has relatively lower mass according to CO_2, thus they frequently collide with each other and have more kinetic energy than CO_2 (P_f/E/S_3).*

> *He(helium) has the more kinetic energy because all medium conditions are the same but molecular mass are different. Because, molecular mass for He is less than that of CO_2 (P_f/E/S_9).*

> *$E_k = \frac{1}{2} m V^2$. The rate of the gas molecules is proportional to their temperature. In this question, temperature is the same both occasion. Therefore, average kinetic energy will be determined by the molecular mass of the gases. So, He has more average kinetic energy (P_f/E/S_{19}).*

> *He is comprised only one atom so, it can just do transnational movement but CO_2 is comprised from three atoms so, can do both transnational and rotational movement. Therefore, CO_2 has more kinetic energy than He gas (P_f/B/S_5).*

The last quotation also indicates that understanding the movements of the molecules of atoms at the molecular level was vague. In addition, there was a considerable proportion of responses that showed sound understanding such as:

> *Kinetic energy is proportional to temperature of the gas molecules. Here, both of them has the same medium temperature value, so their kinetic energy is the same (P_f/E/S_{15}).*

Helium and Carbon Dioxide (In Appendix 2)

Table 4 Students' responses to **Helium and Carbon Dioxide** question in Appendix 2

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	4	6	20	30
2	6	2	30	10
3	5	5	25	25
4	-	1	-	5
5	-	1	-	5
6	5	5	25	25
Total	20	20	100	100

For this question a noticeable proportion of the responses (about 30%) were blank and especially for the part **a**, half of the responses demonstrated that the idea was not understood. However, 25% of responses showed sound understanding.

In this question, students generally used the mathematical approaches rather than using conceptual approaches. They used equations to determine the result but they made mistakes. A common mistake was comparing the volume of the containers such as:

> *Molecules will less interact each other in the container A because it is 1 L. But in container B molecules will more interact each other because volume is less than that of container A. (P_2/B/S_4).*

The same incorrect interpretations were made with the same version of the question in Appendix 1. Finally, this question also revealed that students did not understand the idea of kinetic energy fully. They confused it with collision and velocity of the molecules.

Sea Water (In Appendix 1)

Table 5 Students' responses to Sea Water question in Appendix 1

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	2	10	9	45
2	6	9	27	41
3	3	-	14	-
4	-	-	-	-
5	7	3	32	14
6	4	-	18	-
Total	22	22	100	100

As can be seen from Table 5, 9% of the responses were blank for **a** while this proportion increased dramatically to 45% for **b**. Also, the number of the responses which showed no understanding increased from 27% to 41% from **a** to **b**. The first part of the question was answered partially or fully understand manner by half of the students while 14% of the responses showed partial understandings for **b**. Some responses which showed no understanding for **a** are illustrated below:

> *...Temperature difference is big during the freezing of sea water. In reverse to this entropy change is decreased (P_1/E/S_5).*

Minerals in the sea water increase the solid percentage, and relating with this decreased the entropy. In pure water, entropy change between liquid and solid phases is bigger (P_1/B/S_{11}).

In the answers for **b**, nearly half were blank and the responses given were short, illogical or irrelevant. There were some drawings to show the system - surroundings relationship too.

Sea Water (In Appendix 2)

Table 6 Students' responses to Sea Water question in Appendix 2

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	5	13	25	65
2	5	4	25	20
3	-	1	-	5
4	-	-	-	-
5	7	2	35	10
6	3	-	15	-
Total	20	20	100	100

A few of the respondents answered this question. 25% and 65% of responses for part **a** and **b** were blank respectively. The responses provided did not reveal certain misunderstandings. The first part of the question generally well understood compared to the second part because half of the responses for choice **a** showed partial or sound understanding but this was only 10% for **b**. Responses indicated that students had difficulties in interpreting the diagrams. For exaple:

Diagram **b** has the lowest entropy so, it shows the entropy change for sea water (P_2/E/S_{18})

One of the students related the entropy to the vapour pressure of the water.

***a** for pure water, **b** for sea water. Because, vapour pressure in **b** is less, if vapour pressure became lower ΔS will be small (P_2/E/S_8)*

Some answers for part **b** showed certain misunderstandings as quoted below:

.... during the freezing entropy increases. Therefore, entropy is transferred from the surroundings. So, the surroundings has more entropy (P_2/E/S_{10}).

Some of these responses were theoretically true but they were not a part of the expected answer tor this question.

Energy (In Appendix 1 and 2)

Table 7 Students' responses to Energy question in Appendices 1 and 2

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	3	10	7	24
2	7	16	17	38
3	9	6	22	14
4	4	1	9	2
5	18	7	43	17
6	1	2	2	5
Total	42	42	100	100

The same question in both packages was analysed under one heading. The question asked about the source of the energy in two chemical reactions. In **a,** an exothermic reaction and in **b** an endothermic reaction was represented. Responses spread in a broad range, but the number of sound understanding was very low compared to partial understandings. 7% of responses were blank and 17% of the responses for **a** demonstrated no understanding. Responses demonstrating no understanding with specific misunderstandings and partial understanding with specific misunderstandings were 22% and 9% respectively. Nearly half of the responses demonstrated partial understanding (43%) and only 2% of the sample demonstrated sound understanding.

It was appeared that the reaction in sub-question **a** misled the respondents because the reactants were in gas phase while product was in liquid phase. Therefore, students firstly focussed on the phase change and they thought that energy is given out because of the change of the phase from gas to liquid. They were correct, but they forgot that the energy needed for bond breaking and formation which is also the main contributor of the reaction enthalpy. In the final version of the question the product was given in a gas phase to prevent this misleading.

Some quotations from student responses show that the energy given out in the reaction was as a result of phase change.

> *Molecules changed from gas phase to liquid phase. When they transform from gas to liquid, they will release energy. Thus, energy will be given out* (P_1*/E/*S_1*).*
>
> *Reactants convert from gas to liquid phase to form liquid water. Consequently, condensation gives out energy* (P_1*/E/*S_9*).*

In addition, there were some serious misunderstandings about basic chemical ideas. For example, some of respondents argued that '*bond formation is always exothermic*' (P_1/E/S_{15}) and another expressed the same misunderstanding in a different way by writing:

> ΔH *value for all formation reactions is smaller than zero.....* (P_1*/E/*S_{17}*).*

Some students attributed the energy released in a reaction to the entropy decrease when the reaction occurred because of the phase change from gas to liquid. A few responses showed a basic misunderstanding about differentiating between atom and molecule, and also stability and energy.

> *Atoms in molecular form are more stable. Hence, they have more energy. Thereby, when molecular* H_2 *an* O_2 *react and form* H_2O *molecule, the excess energy is released* (P_1*/B/*S_{11}*).*
>
> *While chemical bonds form, electrons interact each others. When elements convert from atomic form to molecular form, they lost their energy. Thus, energy, is released in the reaction* (P_1*/E/*S_{10}*).*

The second quotation shows that the respondent was not able to recognise differences between the atomic form and molecular form because in the reaction, both H_2 and O_2 are in their molecular forms. In response to the second part of the question, the proportion of the blank responses increased to 24% , and those showing no understanding to 38%. Also, there was 14% showing no understanding with specific misunderstanding. Nearly half of the responses demonstrated partial understandings and only 5% showed sound understanding.

The same misunderstandings were observed for **b** as it was for **a** but there were some contrasts. For example, some students stated that reaction formation was an exothermic process but it also was called an endothermic process in the responses for **b**. Moreover, some of them approached to the sub-question **a** just from the bond formation viewpoint but from bond dissociation point of view for sub-question **b**. Some of them confused the reaction enthalpy with reaction equilibrium and made a comparison between the number of mole of reactants and products as well. A few responses included consideration of entropy and volume changes. One respondent displayed confusion between activation energy and reaction enthalpy.

Gibbs Free Energy (In Appendix 1 and 2)

Table 8 Students' responses to **Gibbs Free Energy** question in Appendix 1and 2

Response Code	Number of responses	Percentage of responses (%)
1	15	35
2	5	12
3	2	5
4	7	17
5	11	26
6	2	5
Total	42	100

Because of the using same question in both packages this was analysed under one heading. As showed in Table 8, one in three of the responses for this question demonstrated 'no response' and there was 12% showing no understanding. Both of these figures constitute nearly half of the responses and this shows that the question was not properly understood or could not be responded to because of the lack of knowledge. Another one third of the responses showed sound understanding. Due to the shortage of the written explanations for the answers given to question no more misunderstandings were revealed. Even this question revealed some confusion about the reaction equilibrium and the value of Gibbs energy at the equilibrium point. Also, some of the respondents could not differentiate between a reaction reaching to equilibrium when $\Delta G = 0$ and goes to equilibrium when ΔG goes to zero. One student considered that reaction **a** and **c** are non equilibrium reaction.

> *In A → B reaction **b** shows that reaction at equilibrium. In equilibrium reaction both A and B are exist. For **a** and **c** curves, reaction goes to one way. Therefore, these are not an equilibrium reactions....* $(P_1/E/S_{13})$.

This explanation displays that the student does not appreciate that all reactions reach an equilibrium at one point.

Potential Energy (In Appendix 1 and 2)

Table 9 Students' responses to **Potential Energy** question in Appendix 1and 2

Response Code	Number of responses	Percentage of responses (%)
1	11	26
2	2	5
3	9	22
4	1	2
5	17	40
6	2	5
Total	42	100

The same question was used in both packages and analysed under one heading. It was an open ended question and a quarter of the responses were blank. Another quarter of the responses demonstrated some misunderstandings and nearly half of the responses showed partial or sound understanding.

This question generated many responses such as :

> It is considered that there is no interaction between the ideal gas molecules and therefore they do not have a potential energy.

Responses also displayed confusion between 'potential energy' and 'energy' such as considering potential energy as the total energy of an ideal gas as can be seen from the following response:

> *Because of the fact that there is no interaction between the ideal gas molecules, they do not have any energy (P_f/B/S_1).*

In addition, some of the responses revealed misunderstandings such as:

> *Potential energy is a position energy, and only fixed molecules have this energy..... (P_f/B/S_7).*
>
> *Potential energy is an energy that needed to bring something to do work. Ideal gas molecules are considered as not to interact each other, they do not need to be ready for doing work. Therefore, potential energy is zero (P_f/B/S_{21}).*

Basically, students considered potential energy as a property.

Explosion in a Strong Steel Box (In Appendix 1)

Table 10 Students' responses to **Explosion in a Strong Steel Box** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	1	5
2	5	22
3	5	22
4	1	5
5	3	14
6	7	32
Total	22	100

This was a multiple choice question but included an explanation section as to why they had chosen the particular option. Nearly half of the responses showed little understanding or no understanding and there was only 5% blank responses. 32% of the responses showed sound understanding and another 14% showed partial understanding. It also generated some misunderstandings.

> *When the explosive has been exploded, the potential energy transforms to kinetic energy and so the entropy increases. Therefore, the system has highest internal*

> *energy after the explosion (P_1/E/S_7).*
>
> *The system is isolated and it does not allow to transfer of heat to the surroundings. The explosion cause an increase of the temperature inside the box and this heat cannot go out and the energy inside the box increases (P_1/B/S_{15}).*

In this question, students generally confused the transformation of energy from one form to another. When the explosion occurred inside the isolated box, it was considered that internal energy increased because of the increased temperature inside the system.

Explosion in a Strong Steel Box (In Appendix 2)

Table 11 Students' responses to **Explosion in a Strong Steel Box** question in Appendix 2

Response Code	**Number of responses**	**Percentage of responses (%)**
1	5	25
2	9	45
3	1	5
4	1	5
5	2	10
6	2	10
Total	20	100

This question generated fewer correct answers. 25% of the respondents did not answer the question and 45% of the responses demonstrated no understanding. It revealed less misunderstandings. Only 10% of the responses showed sound understanding and another 10% showed partial understanding.

The answers were similar to those the multiple choice version. Although responses were not long enough or sufficiently explanatory, it generated the following misunderstandings:

> *I think that the internal energy of the system will increase. If the temperature increases in an isolated system from surrounding, the internal energy will increase (P_2/B/S_{10}).*
>
> *The internal energy is whole energy of the system. There is an movement energy among them. The internal energy will increase because of the increase of movement*

of particles after the explosion (P_2/B/S_{16}).

Only10% of the respondents considered that in an isolated system the internal energy of the system is constant.

Two Spontaneous Reactions (In Appendix 1)

Table 12 Students' responses to **Two Spontaneous Reactions** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	5	23
2	-	-
3	9	41
4	2	9
5	4	18
6	2	9
Total	22	100

This was another open ended question and was intended to encourage the students to put down their own ideas about Gibbs Free energy. Although a significant proportion of the responses (23%) was blank, it generated responses that half of them showed misunderstandings. 18% of the students responses demonstrated partial understanding and 9% of them showed sound understanding.

The common misunderstanding which appeared in nearly one third of the responses was that the smaller negative value of ΔG^o the faster the reaction occurs. A number of responses included a similar explanation. For example:

> *In order to understand that whether the reaction occur spontaneously or not, ΔG^o value must be known or measured. The smaller negative value of ΔG^o, in other words the smaller than zero the faster the reaction occur or spontaneously occur. In this case, the oxidation of Fe occur fast*
> *(P_1/E/S_3).*

In this explanation, there is another misunderstanding where respondent expresses that the value of ΔG^o be measured.

> *I will explain the question by considering physical characteristic of reactants. In the first reaction, gas molecules interact each others but it is hard to react because the possibility of collision of them is low. In the second reaction, the solid molecule will be easily surrounded by gas molecules, hence the reaction occurs quickly. In addition this, it can be judge by examining the ΔG^o value. Since, the lower ΔG^o value, the high probability of occurring reaction (P_1/E/S_9).*

Again in this explanation, the respondent was unable to judge a chemical reaction at a molecular level. In contrast to these responses, there were some explanations that displayed sound understanding as quoted below:

> *I cannot tell anything about the reaction rates by looking to the reaction Gibbs Free Energy values. Gibbs Free energy value gives us an idea about reaction spontaneity and equilibrium...(P_1/B/S_7).*

Rusting of Iron (In Appendix 2)

Table 13 Students' responses to **Rusting of Iron** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	7	35
2	4	20
3	6	30
4	2	10
5	1	5
6	-	-
Total	20	100

This was also an open ended question and was intended to test the students' understanding of reaction rates and Gibbs energy, but one third of the responses was blank. Another 20% of the answers showed no understanding. Also 40% of the responses revealed misunderstandings and a few showed partial understandings (5%) but none of the responses showed sound understanding.

There was no one single correct choice in the question. Any of the choices would be correct. By asking this question, it was intended to reveal whether they believe that there is a relationship between the magnitude of Gibbs Free energy and reaction rate however the question was not mainly understood. Some students related the issue to entropy, spontaneity, and some with reaction rate but many of them failed.

> *The rusting is a slow process. In choice b, the differences between the energy level is so small, hence this may be (P_2/E/S_{12}).*
>
> *ΔG must be negative in order to occur the reaction. If we think that reaction happens slowly, it is expected that ΔG mus be come down from a high positive value to a low negative value. I mean, the beginning ΔG value must be high. This is shown in the diagram a (P_2/E/S_{16}).*

Perfect Gas (In Appendix 1)

Table 14 Students' responses to **Two Spontaneous Reactions** question in Appendix 1

Response Code	**Number of responses**	**Percentage of responses (%)**
1	1	5
2	3	13
3	9	41
4	-	-
5	7	32
6	2	9
Total	22	100

This question examines the students' understanding of the internal energy change during an isothermal expansion and it was a multiple choice question. As can be seen from the Table 14, only one student left the question as blank. It revealed a number of misunderstandings. 41% of the responses were considered as containing no understanding with specific misunderstandings. Nearly 40% of the responses showed partial or sound understandings.

The main misunderstanding was that internal energy was considered as only proportional to the velocity of the gas molecules. Also, it was related to the volume of the container and hence with the collision of molecules. This misunderstanding was identified in many responses as shown in the examples:

> *The internal energy of gas depends on its' volume. Intermolecular interactions are more in A. in B these decrease and internal energy will decrease (P_1/E/S_{11}).*

> *The internal energy will increase. Because, gas molecules can be move easily when the volume of them increase. Internal energy is total energy of particles (P_f/E/S_{13}).*
>
> *If the volume of gas increases, the probability of the collision of gas molecules will decrease, thereby the internal energy will decrease (P_f/E/S_{21}).*
>
> *The probability of colliding to the inside surface of the container of gas molecules will decrease, therefore, the internal energy of them will decrease (P_f/B/S_{19}).*

There were some responses showed sound understanding as quoted below.

> *In these two system, average kinetic energy of the gas molecules does not change, because their temperatures are the same. When the volume of container increases, the probability of collision of gas molecules will decrease, but their kinetic energy will stay at the same value. Therefore, the internal energy will not be affected from the volume changes at the same temperature (P_f/B/S_9).*

Perfect Gas (In Appendix 2)

Table 15 Students' responses to **Two Spontaneous Reactions** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	1	5
2	7	35
3	5	25
4	-	-
5	7	35
6	-	-
Total	20	100

This version of the question was completely open ended and did not generate any sound understanding responses, but one third of the sample showed partial understanding. 25% of the responses showed misunderstandings. Again, only one respondent did not respond to the question but another one third displayed no understanding.

The same mistakes were made as with the multiple choice version. In addition to them, some students' responses showed that they could not comprehend the idea tested in the question and tried to give an answer by using mathematical equations, as in this case.

> $\Delta U = \Delta H + P\Delta V \rightarrow \Delta U = \Delta H + nRT \ln 2$
> *The internal energy will increase by nRT ln2 (P_2/E/S_{16}).*

One response showed no understanding of the word ***isothermally*** confusing with ***adiabatic.***

> *The internal energy is; U = q + w. The heat does not change because of isothemally volume increases. Because, the container isothermal (no transfer of heat)... (P_2/E/S_{18}).*

ΔG° and Temperature Change (In Appendix 1 and 2)

Table 16 Students' responses to ΔG° **and Temperature Change** question in Appendix 1and 2

Response Code	Number of responses	Percentage of responses (%)
1	17	40
2	20	48
3	2	5
4	-	-
5	3	7
6	-	-
Total	42	100

Since the same question was used in both packages it was analysed under the same heading. This was a question intended to test students' ability to recall how ΔG° changes with temperature but as seen from Table 16, 40% of the responses were blank, also another 48% of responses showed no understanding and further 7% of the responses showed partial understanding.

Most of the respondents appeared to guess the answer as there were no explanations why the particular answer had been given. The limited number of explanations given were in fact a repetition of ideas provided in the question. Some of the students tried to use the equation $\Delta G = \Delta H + T\,\Delta S$ to solve the problem along with other physicochemical equations. Moreover there were some explanations that accepted the reaction as endothermic or exothermic and then provided an answer.

Water (In Appendix 1)

Table 17 Students' responses to Water question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	1	5
2	1	5
3	5	22
4	5	22
5	7	33
6	3	13
Total	22	100

This question aimed to test the students' understanding of internal energy change and was administered as both multiple choice and open ended versions. The results from the multiple choice version showed that most of the students were encouraged to put their ideas down. Only one respondent did not answer the question and also one response showed no understanding. Respectively, 22% of the responses showed no understanding with specific misunderstandings and another 22% showed partial understanding with specific misunderstandings. A considerable proportion of the responses showed partial understanding (33%). 13% of responses showed sound understanding.

The question generated several misunderstandings as students considered that the internal energy would change with the temperature and volume changes, but did not realise that by stirring the water work is done on the system and therefore causes an increase in its temperature. Another misunderstanding was that the internal energy changes were as a result of molecular collisions. The quotations below indicate these misunderstandings:

> *In the first beaker, molecules will move quickly because of the increase in their temperature, hence the internal energy increases. In the second beaker, stirring does not affect the movement of molecules (P_1/E/S_{15}).*
>
> *The internal energy is only function of volume and temperature. Therefore, if the temperature of beaker increases, the internal energy will increase. The internal energy of second beaker does not change (P_1/E/S_{19}).*
>
> *Since both of the systems are not isolated, different energy transformations occur*

and, so the internal energy stays constant ($P_1/B/S_{11}$).

When the first beaker heated, the intermolecular interactions increase. Since the kinetic energy of molecules increase, the internal energy increases. In the second beaker, stirring is a physical process, and it does not changes chemical structure of water. Thereby, the internal energy does not change ($P_1/E/S_{13}$).

Water (In Appendix 2)

Table 18 Students' responses to Water question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	3	15
2	1	5
3	6	15
4	8	40
5	3	15
6	2	10
Total	20	100

This open ended version of the question also revealed some misunderstandings, but the percentage of blank responses increased to 15%. There were misunderstandings in more than half of the responses and a quarter of the responses showed partial and sound understandings.

The same misunderstandings were repeated in this version of the question but there were some differences possibly due to the structure of the question as quoted below.

In the second beaker, reaction equilibrium stay constant as a result of stirring

$$H^+ + OH^- \rightarrow H_2O_{(l)}$$

Therefore, reaction enthalpy does not changes. That means the internal energy will stay constant.

In the second beaker, since the temperature increases, ΔH changes. Because the reaction is exothermic, the internal energy increases.(Temperature changes affect the equilibrium) ($P_1/E/S_{16}$).

This response shows that the respondent did not understand the question fully because there was no chemical reaction mentioned in the question. In another response, the correct equations were stated but interpreted incorrectly. The equation may have been memorised without being understood.

> *The internal energy increases in the first beaker. $\Delta U = q + w$. The heat supplied to the first beaker by q. The internal energy does not change in the second beaker (P_2/B/S_4).*

The respondent states the correct equation but cannot understand the "w" in the equation, where "w" shows the work done on the system causes an increase in the internal energy of the second beaker and its contents.

Gibbs Free Energy Changes with Temperature (In Appendix 1)

Table 19 Students' responses to **Gibbs Free Energy Changes with Temperature** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	7	32
2	3	13
3	-	-
4	-	-
5	5	23
6	7	32
Total	22	100

This question was intended to test students' knowledge about changes of Gibbs Free energy with the temperature of three phases of matter. The question failed to generate misunderstandings and also 32% of the sample left it as blank. 23% of responses showed partial understanding and 32% of them showed sound understanding. Typical responses were:

> *Gases are more affected from the temperature changes than solid and liquids. So, choice "**a**" must be correspond for gases (P_1/E/S_{19}).*
>
> *The temperature changes most likely affects the gas phases, therefore the sharpest decrease must be correspond to Gibbs Free energy change (P_1/E/S_{21}).*

Gibbs Free Energy Changes with Temperature (In Appendix 2)

Table 20 Students' responses to **Gibbs Free Energy Changes with Temperature** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	3	15
2	-	-
3	1	5
4	-	-
5	4	20
6	12	60
Total	20	100

In this version, students were asked to match the graphs with the gas, liquid and solid phases of the matter and generated more correct answers than the previous version. Again it failed to reveal the students' misunderstandings.

The responses generally included explanations of entropy changes and also how temperature affects the gas phase of matter. There were many similar responses of which the following as an example:

> ***a** for gas, **b** for liquid and **c** for solids. There is a gas phase in **a**. Because entropy increases with temperature increase. When the entropy increases, the decrease in the ΔG will increase... (P_2/E/S_8).*

Mixing of Gases (In Appendix 1 and 2)

Table 21 Students' responses to **Mixing of Gases** question in Appendix 1and 2

Response Code	Number of responses			Percentage of responses (%)		
	a	b	c	a	b	c
1	4	9	8	10	21	19
2	6	10	12	15	24	29
3	15	13	3	36	31	7
4	2	1	-	5	2	-
5	12	4	13	29	10	31
6	2	5	6	5	12	14
Total	42	42	42	100	100	100

Since the same question was asked in the both packages it was analysed under one heading. This question consists of three sub-questions which are denoted by **a**, **b**, **c**, and each one is open ended.

In response to **a**, 10% of the responses were blank, 15% showed no understanding and almost 40% of responses included some misunderstandings. The remainder of the responses showed partial understanding (29%) and sound understanding (5%).

Most of the students thought the increase of entropy to be as a result of an increase in volume and an increase in the randomness of gases. Some of them attributed it to the decrease of partial pressure of the gases which is also correct. Some of these explanations were considered as correct or partially correct. However, there were some incorrect explanations as illustrated below:

> *When the gas molecules mixed, the number of collision of them will increase, thus entropy increases (P_1/E/S_3).*

One of the respondents attributed the increase in entropy to the increase of the number of molecules after a collision of gas molecules as quoted below:

> *When the tap is opened, the gases will be mixed and then the number of collisions will increase. That means that the number of gas molecules increase and so entropy increases (P_1/E/S_{14}).*

The responses given to **b** showed less understanding and 21% of the responses were blank ans also 24% of the responses demonstrated no understanding. Nearly one third of the responses showed some misunderstandings, 12% showed sound understanding and another 10% partial understanding.

This sub-question concerned how the enthalpy changes occurred during the mixing of gases. Under the constant pressure and temperature the enthalpy change is zero, but many students considered that enthalpy would increase during the process as a result of the movement of gas molecules because they would give out energy as heat. Some of the respondents thought that enthalpy only changes with the changes in volume and so enthalpy would increase in this process.

In response to sub-question **c**, there were more correct answers and less misunderstandings. A significant proportion of the responses were blank (19%) whilst 29% showed no understanding. 7% of the responses included misunderstandings, one third showed partial understanding and 14% a sound understanding.

The main misunderstanding was the idea that Gibbs free energy will increase in a spontaneous process. Students did not thought ΔG itself in a spontaneous change, but tried to explain it by using ΔH and ΔS changes which they guessed before the process. When they made a mistake about the changes in ΔH and ΔS they also made the same mistake when guessing the changes in ΔG. Some of them thought of the process after reaching the equilibrium and so responded that there would not be a change in ΔG.

Magnesium (In Appendix 1and 2)

Table 22 Students' responses to **Magnesium** question in Appendix 1and 2

Response Code	Number of responses		Percentage of responses (%)	
	a	b	a	b
1	12	20	29	47
2	15	7	35	17
3	5	2	12	5
4	3	4	7	10
5	5	6	12	14
6	2	3	5	7
Total	42	42	100	100

This question was posed in the same form in both packages, so it was analysed under the same heading. The question was set to determine the students understanding of internal energy and enthalpy, and this generated less sound understanding responses and more no understanding. There was a relatively high proportion of blank responses for **a** (29%) and no understanding responses (35%). Nearly one fifth of the responses showed some misunderstandings and 12% of answers showed partial understanding. Only 5% of the sample displayed sound understanding. However, some queries about the structure of the diagram associated with the question arose during the discussion with students. Some could not understand the diagram and complained that there was not efficient explanation. In the final version of the question the diagram was redrawn in a larger format

The misunderstandings observed were about basic chemical ideas like system and its surroundings and the effusion of gases. The responses quoted below shows these misunderstandings.

> *This is an exothermic reaction and gives heat to the surroundings. When the tap is opened, the heat given to surroundings will be more. In this occasion the heat evolves will transfer into the piston, and thus the heat will be transferred to the surroundings which out of the system... (P_2/E/S_2).*

As seen from the responses The respondent was not able to recognise the boundaries between the system and its surrounding. In another response it was stated that:

> *The more heat will be given out in the diagram **a**. Because, the gas will effuse very quickly in the medium or in the reaction. The heated gas can heat the surrounding more quickly and more effectively (P_2/B/S_2).*

In responses given to sub-question **b**, 47% of the responses were blank and another 17% showed no understanding. 15% of the included some misunderstandings and 7% responses demonstrated sound understanding.

In one of the responses, the respondent attributed the enthalpy change to the reaction which occurs only in one way:

> *The heat is given out in the system **b** shows the changes in the reaction enthalpy. I don't have any idea about the internal energy changes where it happens. **b** shows the enthalpy changes because the reaction occurs in one way (P_1/E/S_{13}).*

Some of the respondents confused the internal energy with its' equation $\Delta U = q + w$. Because of w in the equation they thought that the heat is given out in the system **a** is equal to the internal energy, since the gas does work by pushing the piston and hence that must be the internal. This kind of response shows that students were not able to recognise the differences between internal energy and enthalpy and so what causes a change in the value of these terms.

a → shows the change in internal energy, $\Delta U = q + w$: does work.
b → shows the change in enthalpy : there is no work (P_1/B/S_5).

Entropy Change (In Appendix 1)

Table 23 Students' responses to **Entropy Change** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	13	63
2	1	5
3	1	5
4	1	5
5	3	13
6	2	9
Total	22	100

This question asked how Gibbs free energy changes with the changes in entropy. On a diagram, entropy changes for the Haber process was given and then students were asked to determine how Gibbs free energy changed by drawing it on the same graph. As can be seen from Table 23, 63% of the sample did not respond to the question and a few misunderstandings were revealed. Nearly one fifth of the students showed partial understanding (13%) and a further 9% showed sound understanding.

When they were asked to make a comment about the structure of the question, they complained that they had not been shown how to draw two ordinated graphs. Perhaps that would explain why such large number of students left the question blank. The most common misunderstanding was drawing Gibbs free energy changes as a linear decrease or parallel to x axis.

Entropy Change (In Appendix 2)

Table 24 Students' responses to **Entropy Change** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	14	70
2	1	5
3	1	5
4	1	5
5	3	15
6	-	-
Total	20	100

Here, the previous question was asked in the reverse form. This time Gibbs free energy change was shown on the graph and the students were asked to draw a graph that reflects the change in entropy. Again, the majority of students left the question blank (70%) and a few number of the responses showed sound understanding. Only 15% of the responses demonstrated partial understanding. The same point arouse from the discussion as with the previous question. Some students considered that entropy will stay constant and some entropy will increase but drew it wrongly.

Two Hypothetical Reactions (In Appendix 1)

Table 25 Students' responses to **Two Hypothetical Reactions** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	3	13
2	-	-
3	7	32
4	6	27
5	6	27
6	-	-
Total	22	100

This question tests the students' knowledge of the reaction rates. It generated many misunderstandings as shown in Table 25 however only a small number of students did not answer the question. 60% of the responses showed some misunderstandings and another quarter demonstrated partial understanding. There was no response showing sound understanding.

The most common misconception was that exothermic reactions are always faster than endothermic reactions. In addition some students argued that the more negative value of ΔG, the faster the reaction occurs. Another similar misunderstanding was that if a chemical reaction occurs spontaneously, it always happens faster.

> *....Here, reaction 1 happens spontaneously, because of occurring spontaneously, this reaction goes faster. Because, if we supply heat it makes the reaction slow (P_1/E/S_7)*

From this quotation another misunderstanding is evident and that is that endothermic reactions cannot occur spontaneously. Moreover, one respondent states that the rate of the reaction has been determined by the Gibbs free energy of the reaction. Finally, in another response it was asserted that the temperature does not affect the reaction rates as quoted below.

> *The first reaction occurs fast. Because, it does need to get heat from its surroundings. I mean, the temperature at which reaction occurs is not important. However, endothermic reaction need some heat to occur. That means, the reaction happens with the accompany of temperature (P_1/B/S_{15}).*

Two Hypothetical Reactions (In Appendix 2)

Table 26 Students' responses to **Two Hypothetical Reactions** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	-	-
2	2	10
3	10	50
4	4	20
5	4	20
6	-	-
Total	20	100

This question was the open ended version of previous question asked in Appendix 1. None of the respondents left it blank and 70% of the responses showed some misunderstandings. 20% of the responses showed partial understanding but none showed a sound understanding.

Similar misunderstandings were observed in this open ended version of the question with the multiple choice version. Most of the students thought that endothermic reactions occur more slowly than exothermic reactions. In addition there was some new misunderstandings:

> *The reaction rate is depends on the actual magnitude of the energy given out or supplied to the reaction, and the reaction occurs with less amount of energy will occur fast..... (P_2/E/S_{12}).*

Some responses stated that if the reaction occurs at the same temperature they happen at the same rate because they have the same kinetic energy value.

Gibbs Free Energy (In Appendix 1)

Table 27 Students' responses to **Gibbs Free Energy** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	9	41
2	2	9
3	1	5
4	5	23
5	3	13
6	2	9
Total	22	100

This was an open ended question and students were given a table to show the value of ΔG against the extent of the reaction. they were asked to determine where the reaction reached the equilibrium, but again a large percentage of the respondents did not answer the question (41%). Another 9% of them had no understanding and 9%of them showed sound understanding. There was 13% partial understanding and one third of the responses showed some misunderstandings.

They considered that where the extent of reaction value was close to zero the reaction reached equilibrium there.

> *At 0,1. Because when $\Delta G = 0$ the equilibrium would be 0,1 is the close number to zero, so it would be (P_1/E/S_7).*

There were some responses which stated that the reaction reached the equilibrium where the changes reached a minimum value between the ΔG values.

Gibbs Free Energy (In Appendix 2)

Table 28 Students' responses to **Gibbs Free Energy** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	3	15
2	1	5
3	2	10
4	2	10
5	8	40
6	4	20
Total	20	100

This was also an open ended question and students were given three different drawings on the same graph and asked to determine which one of them would belong to an equilibrium reaction. More than half of the responses showed partial understanding(40%) and a further 20% demonstrated sound understanding. 15% of the respondents left the question blank and one fifth included misunderstandings. Some respondents chose graph **a** and explained that when the reaction goes from A → B, Gibbs free energy value will decrease.

> *The answer is a. because in order to occur the reaction from A → B, Gibbs energy must be decrease (P_2/B/S_{16}).*

Spontaneous Change (In Appendix 1)

Table 29 Students' responses to **Spontaneous Change** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	5	23
2	12	55
3	3	13
4	1	5
5	1	5
6	-	-
Total	22	100

In this question, the entropy change during a spontaneous change was examined, but nearly all of the respondents failed to give the correct answer. More than half of the responses showed no understanding at all (55%) and 23% were blank. Only one response was considered as partial true and few misunderstandings were observed. Students could not understand the idea tested in the question. They mainly focussed on the phase changes from liquid to solid and considered that entropy would decrease because of the increase in the order of molecules in the solid for. Noone considered that the reaction occurs spontaneously and all spontaneous changes produce an increase in the entropy of system. Here, the system was a closed system and when the crystallization occurs the temperature of the medium increases because of the energy given out as a result of ordering of molecules and this cause an increase in the entropy. This is probably because of the fact that entropy is only considered as disorder or randomness rather than the probability of being in a different energy level.

Spontaneous Change (In Appendix 2)

Table 30 Students' responses to **Spontaneous Change** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	8	40
2	3	15
3	7	35
4	1	5
5	1	5
6	-	-
Total	20	100

In this version, the same question was asked in a completely open ended form. Again 40% of the respondents left it blank and none showed sound understanding. A relatively high proportion of the responses showed misunderstandings in this version (40%).

Some students thought that this process is reversible process and that there would not be any change in the entropy of the system. Similar misunderstandings with multiple choice version were also seen. They mainly approached entropy from the randomness and disorder points of view.

Ice Melting (In Appendix 1)

Table 31 Students' responses to **Ice Melting** question in Appendix 1

Response Code	Number of responses	Percentage of responses (%)
1	1	5
2	8	36
3	3	13
4	1	5
5	1	5
6	7	32
Total	22	100

In this open ended question students generally failed to determine the solubility enthalpy values of NaCl and KI endothermic and exothermic. The question was misunderstood in general therefore the responses were included incorrect answers. Some accepted the reaction as exothermic and responded incorrectly but 32% showed sound understanding. 36% of the responses showed no understanding and 18% showed some misunderstandings.

The common confusions were the system and its surroundings and freezing and melting. In this question there was no freezing but students still considered freezing when they evaluated the melting of ice. These kind of responses can be attributed to misunderstanding what the question was asking.

Ice Melting (In Appendix 2)

Table 32 Students' responses to **Ice Melting** question in Appendix 2

Response Code	Number of responses	Percentage of responses (%)
1	2	10
2	4	20
3	2	10
4	3	15
5	4	20
6	5	30
Total	20	100

In this version, the same question was asked differently and showed a more reliable distribution of the responses to each of the coding schemes. Only 2 respondents left it blank and 20% showed no understanding and one quarter of the responses included some misunderstandings. Half of the responses showed partial understanding (20%) and sound understanding (30%).

Although it was stated that during the solubility heat was absorbed from the water, some respondents did not consider this and judged them as exothermic reactions.

Gibbs Free Energy Change with Pressure (In Appendix 1 and 2)

Table 33 Students' responses to **Gibbs Free Energy Change with Pressure** question in Appendix 1and 2

Response Code	Number of responses	Percentage of responses (%)
1	13	31
2	-	-
3	-	-
4	3	7
5	13	31
6	13	31
Total	42	100

Since the question was asked in the same form it was analysed under the same heading. Students showed more understanding and only a few misunderstandings were identified. Nearly one third of the responses were blank and a similar proportion showed partial understanding (31%) and 31% of the responses showed sound understanding.

One of the misunderstandings that occurred infrequently states that Gibbs energy only applies to solutions and gases. Another one stated that Gibbs energy is increased only with the increase of collision of gas molecules.

Carbon Dioxide and Propane (In Appendix 1 and 2)

Table 34. Students' responses to **Carbon Dioxide and Propane** question in Appendix 1 and 2

Response Code	Number of responses	Percentage of responses (%)
1	10	24
2	6	14
3	11	27
4	6	14
5	3	7
6	6	14
Total	42	100

This question was also asked in the same form in both packages and analysed under the same heading. 24% of the responses were blank and 14% of the answers were incorrect and nearly 40% of the responses displayed some misunderstandings. One fifth of the responses showed partial understandings and 14% showing sound understanding.

The most common misunderstanding was that the smaller the molecular structure, the more quicker movement of particles, a higher kinetic energy and therefore a higher entropy value. Many responses generated such answers:

> *The entropy of CO_2 is more than C_3H_8. Because, CO_2 has the less molecular weight and self volume. Therefore, CO_2 molecules move easily. Hence, the disorder increases (P_1/B/S_3).*

Here, The respondent did not realise that both molecules have the same weight. In some of the other responses it was stated that entropy values are the same at the same temperature and it only depends on the temperature change. In addition, some of them related the entropy changes to only temperature and volume of the matter and therefore concluded that entropy values of both gases were the same. There was another response which expressed that entropy is independent from the mass of the matter.

> *Entropy is independent from the mass. The free movement of CO_2 is more than C_3H_8. I mean, disorder is more. If the disorder increases, the entropy will increase (P_2/E/S_{18}).*

Students perhaps confused the kinetic energy with entropy because they memorised the definition of entropy as a measure of disorder and randomness.

Appendix 8

The Questions and the Expected Answers

Internal Energy and Related Ideas

Five questions *Helium and Carbon Dioxide, Potential Energy, Perfect Gases, Explosion in a Steel Box* and *Water* probe students' understanding of internal energy and related ideas. Some of the questions examine topics should be known before learning internal energy and some examine the understanding of the internal energy itself.

Helium and Carbon Dioxide

a)

Contains He
n = 1 mol
V = 1 L
T = 298 K

Contains CO_2
n = 1 mol
V = 1 L
T = 298 K

The two containers are shown here. One of them contains 1 mol He and the other contains 1 mol CO_2 at the same temperature .

How does the average kinetic energy of the molecules of helium with that of the molecules of carbon dioxide? Explain your answer as carefully as you can.

b)

Contains He
n = 1 mol
V = 1 L
T = 298 K

A

Contains He
n = 1 mol
V = 0,5 L
T = 298 K

B

The two containers contain one mole of 1 mol He at the same temperature.

What do you think is the average kinetic energy of the molecules of helium in these containers. Explain your answer as carefully as you can.

This question tests the of students' ability to recall the knowledge about kinetic energy which is a fundamental idea and should be understand in order to understand the internal energy. Kinetic energy is generally recalled from the physical point of view rather than chemical viewpoint. The question is composed of two sub-questions, but the same idea is being tested in both of them.

The idea being tested is: The average kinetic energy of atoms or molecules is the same at the same temperature. It does not change by changing the volume of the container, providing the atoms or the molecules are kept at the same temperature.

The expected answer is: Kinetic energy is the energy that a body (a block of matter, an atom, or an electron) possesses by virtue of its motion. The average kinetic energy of a collection of bodies is proportional to the temperature of the collection of bodies. Thus, the average kinetic energy of gas molecules, He and CO_2, is the same for both of the sub-questions because their temperature is the same on both occasions.

Potential Energy

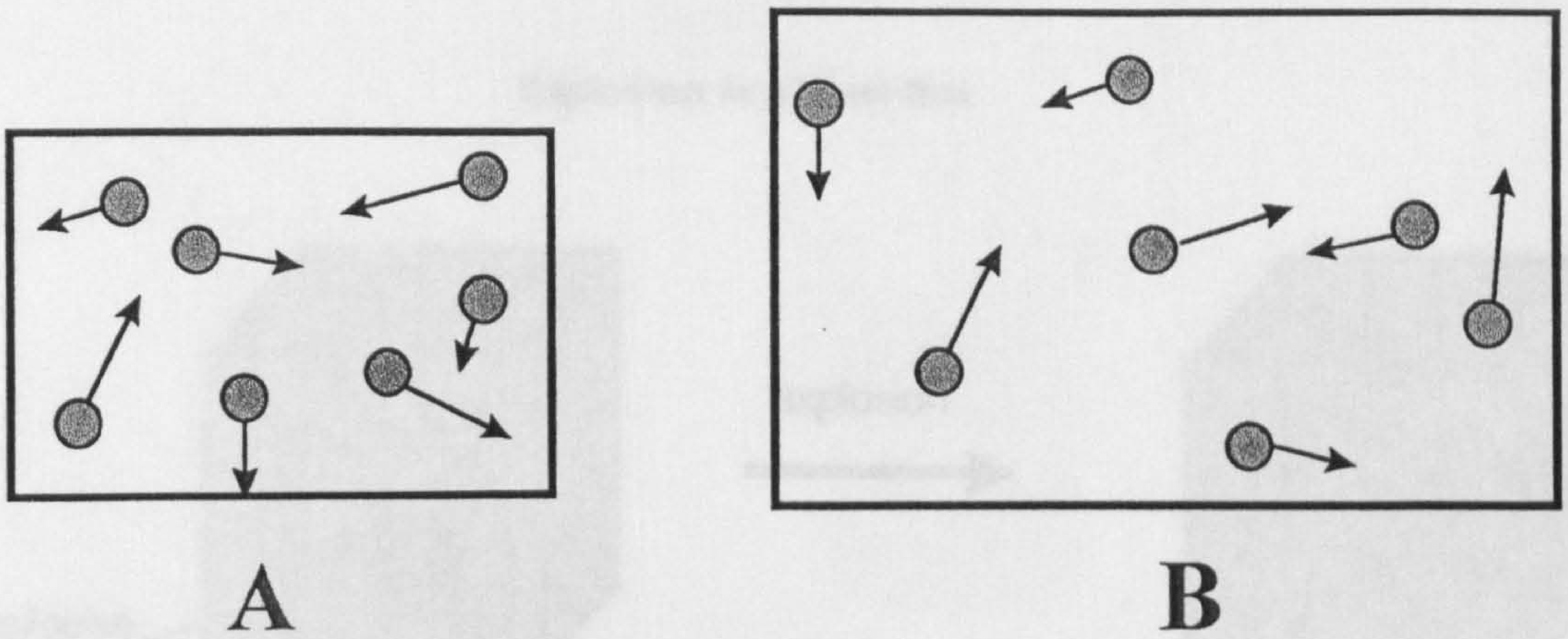
The potential energy of perfect gas molecules is assumed as zero. Why?, Explain as carefully as you can.

This is also a very simple and essential idea in thermodynamics as both potential and kinetic energy contribute to the internal energy.

The idea being tested is: The potential energy of perfect gas molecules is assumed as zero as stated in the question.

The expected answer is: The potential energy of a body (this can be an electron, nucleus, particle etc.) is the energy due to its position. However, this question considers tiny gas particles. Here, the source of the potential energy is the attraction and repulsion forces between the gas molecules or atoms. When a charged body is in the vicinity of another charged body it acts on the charge carried by the body and they have potential energy. Also, when two real gas particles collide they lose some of their kinetic energy and it is stored as potential energy in the body of the collided particles. However, it is assumed that there is no interaction between ideal gas particles and it is also supposed that if they collide these collisions are perfectly elastic in which energy transfer (i.e. from kinetic to potential energy) does not occur. In an elastic collision the sum of the kinetic energy of the collided particles is the same before and after the collision. Therefore, ideal gas molecules or atoms are assumed as having zero potential energy.

Perfect Gases



There is a perfect gas in a vessel (**A**) at a particular temperature. The volume of vessel is doubled (**B**) *isothermally* (this means temperature stays the same).

What happens to the internal energy of the gas after the expansion? Explain your answer as carefully as you can.

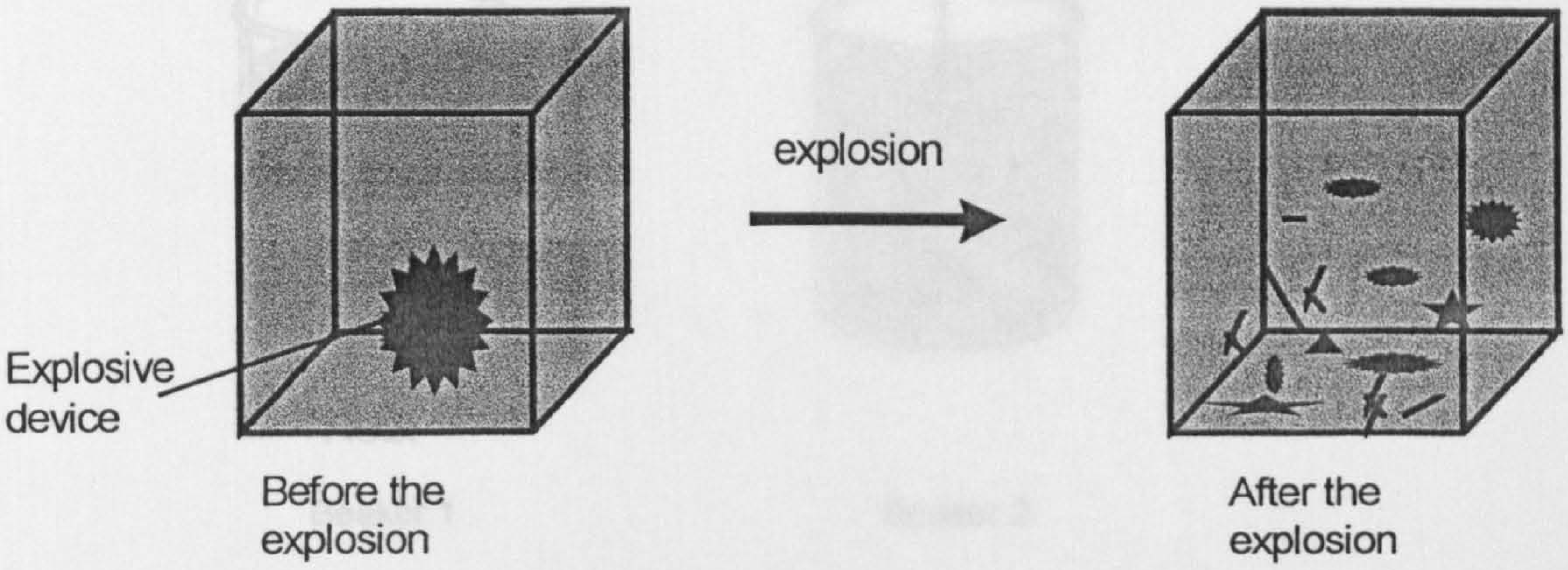
Perfect Gases is a combination of both kinetic and potential energy and its application to the internal energy. The drawings are adapted from Atkins (1997, p 99). The length of arrows and the numbers shown are the same in both vessels, but their directions are random.

<u>The idea being tested is</u>: The internal energy is the sum of the kinetic energy of all the particles and the potential energy arising from their interactions with one another.

<u>The expected answer is</u>: At a particular temperature, a perfect gas consists

of a collection of molecules that have a certain kinetic energy and zero potential energy (as explained in *Potential Energy*) when the volume of gases is increased isothermally. At the same temperature, the mean kinetic energy remains the same, hence the arrows are shown as being the same lengths and the potential energy remains zero. Thus, the internal energy of a perfect gas remains the same. No change can be observed in the internal energy of gas if the expansion of gas happens under isothermal conditions.

Explosion in a Steel Box



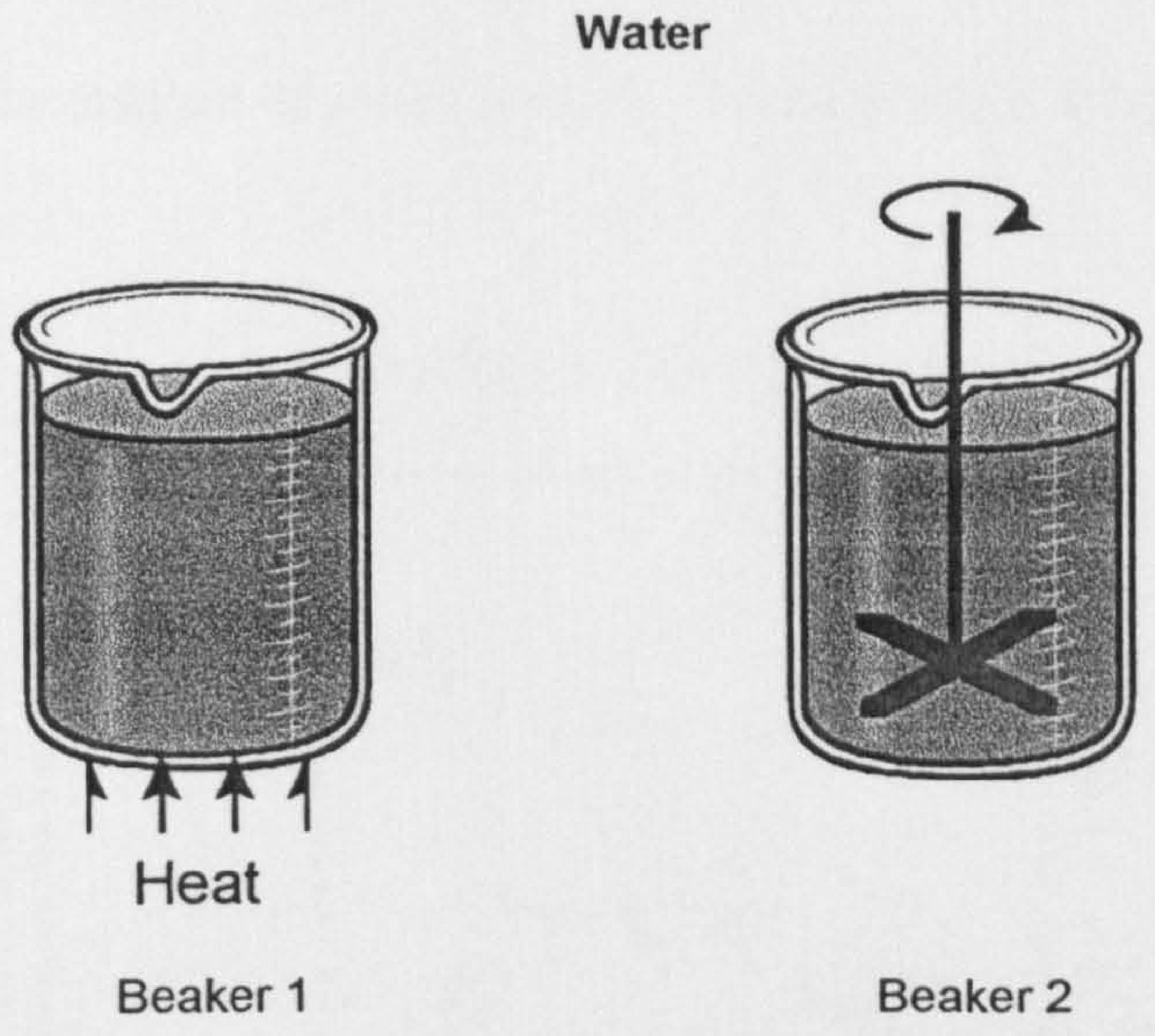
Imagine that an explosive device was placed in a thermally insulated strong steel box. Then the device is exploded within the insulated box. After the explosion, the temperature and the pressure in the box have increased. The whole system consists of the solid matters from the exploded device, the steel box and the various gases in the box.

How does the internal energy of the whole system compare before and after the explosion? Explain your answer as carefully as you can.

This particular question probes the students' ability to apply the first law of thermodynamics to a problem. An explosion analogy has been chosen because many chemical changes happen during an explosion with some bonds being broken, some being formed and heat being released. All represent energy transformations but the total energy remains the same in the insulated box after the explosion.

The idea being tested is: The internal energy of an isolated system is constant (First law of thermodynamics: we cannot create or destroy the internal energy.)

The expected answer is: The internal energy of the system remains the same after the explosion because the system is isolated and there is no energy transfer from either the system to its surroundings or vice versa. Energy transformations take place within the system but the internal energy remains the same.



Two identical 1 litre glass beakers each contain 900 cm^3 of water. At the start, both beakers are at room temperature (25 °C). Later, Beaker 1 is heated by a candle for five minutes while Beaker 2 is stirred vigorously for five minutes.

How will the final internal energies of the two beakers and their contents compare with their initial internal energies? Explain your answer as carefully as you can.

This question tests another basic fact about internal energy that both heating and doing work on a system cause a change in the internal energy of the system.

The idea being tested is: The internal energy change of a system is equal to the heat gained or released in the system or work done by the system or on the system, or both of them. Therefore, the internal energy of a system can be altered by doing work or by heating.

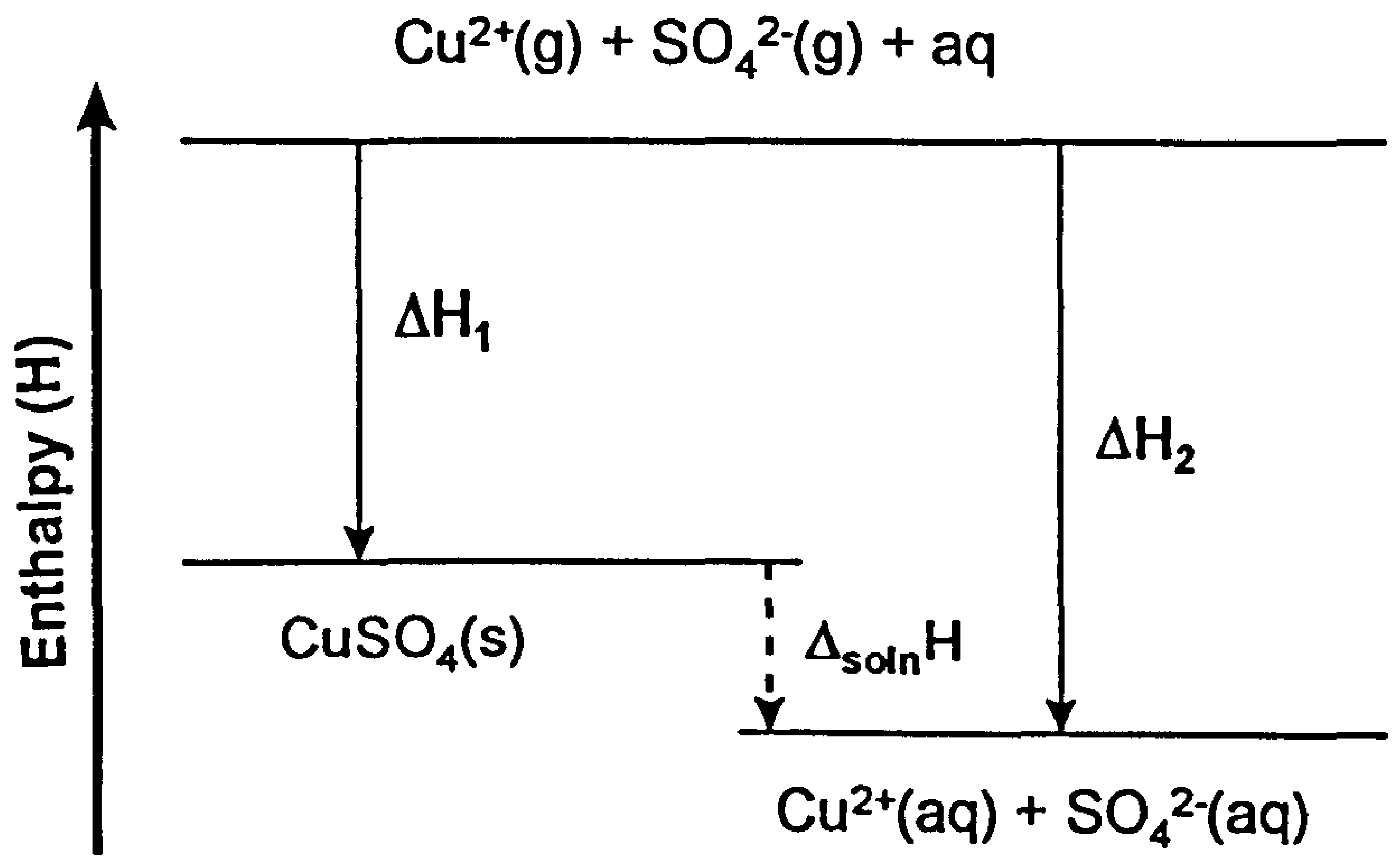
The expected answer is: Both transferring energy as heat or doing work on the system cause an increase of the internal energy of the system. Therefore, in both beakers the final internal energies are increased from their respective initial levels.

Enthalpy and Related Ideas

These questions probe students' understanding of enthalpy and related ideas. Five questions, *Copper(II) Sulphate, Energy, Magnesium, Two Hypothetical Reactions* and *Ice Melting*, were posed. Some of them were intended to explore the students ability to recall basic ideas and others were intended to test students' understanding of enthalpy.

Copper(II) Sulphate

An energy-level diagram is shown below for the dissolving of anhydrous copper (II) sulphate.



a) Write down the name of enthalpy changes indicated by ΔH_1 and ΔH_2 on the diagram into the provided gaps below.

ΔH_1 is.., ΔH_2...

b) Draw an arrow on the diagram above to represent the enthalpy of solution ($\Delta_{soln}H$) of $CuSO_4(s)$.

c) Would you expect the temperature of the water to rise or fall when anhydrous copper(II) sulphate dissolves? Explain your answer.

This question is adapted from an Oxford and Cambridge Schools Examination Board, Advanced Level Chemistry Exam Paper (1993). It tests both recall and understanding. The first two sub- questions (**a** and **b**) examine students' ability to recall essential definitions about enthalpy. The final sub-question (**c**) concerns the energy level diagram of an exothermic reaction. The diagram is redrawn to reflect changes made to the questions. The important point on the diagram is the direction of the arrows because this determines the name given to the enthalpy changes.

The idea being tested is: The change in lattice enthalpy, hydration and solution, and the determination of the type of the reaction by considering at the energy level diagrams.

The expected answers are:

a) ΔH_1 is lattice enthalpy

ΔH_2 is hydration enthalpy

There is some inconsistency about the definition of lattice enthalpy which needs to be clarified. Lattice enthalpy is defined in two ways in the textbooks. The first definition is the energy change when one mole of a crystal is formed from its component ions in the gaseous state (Matthews, 1996, p.263). According to this and other similar definitions, all lattice enthalpies are negative. The second definition is the opposite of the first that the lattice enthalpy is the standard change in enthalpy when a solid substance is converted to a vapour, as in the process $MX_{(s)} \rightarrow M^+_{(g)} + X^-_{(g)}$ for an ionic solid or $A_{(s)} \rightarrow A_{(g)}$ for a molecular covalent solid (Atkins1995, p.199). According to this definition all lattice enthalpies are positive. IUPAC also accepts the second definition for lattice enthalpy (Lide, 1999; **12-22**). However, ineffective of the definition used, the only difference is the sign of the lattice enthalpy. Its sign would either be positive or negative but its magnitude would be the same in both cases.

b) It is shown on the question diagram as a dotted arrow.

c) From the energy level diagram, it is clear that the reaction is an exothermic reaction, hence when the anhydrous copper (II) sulphate dissolves in water the temperature will increase.

Energy

a) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g) \qquad \Delta_f H^\ominus = -242\ \text{kJ mol}^{-1}$

This thermochemical equation tells us that 242 kJ of energy are released as heat at constant pressure when 1 mol H_2 molecules reacts with ½ mol O_2 to form 1 mol H_2O.

Explain as carefully as you can why energy is released in this reaction.

b) $N_2(g) + 2\,O_2(g) \rightarrow 2\,NO_2(g) \qquad \Delta_f H^\ominus = 68\ \text{kJ mol}^{-1}$

This thermochemical equations tells us that heat is required at constant pressure when 1 mol N_2 reacts with 2 mol O_2 to form 2 mol NO_2.

Explain as carefully as you can why heat is required in this reaction.

This question tests one of the most confused idea about sources of energy in a chemical reaction. It is designed both for exothermic and endothermic cases to get a broad range of responses.

The idea being tested is: The enthalpy change of a reaction depends on the overall strengths of the bonds of molecules and/or compounds of the reactants and the products.

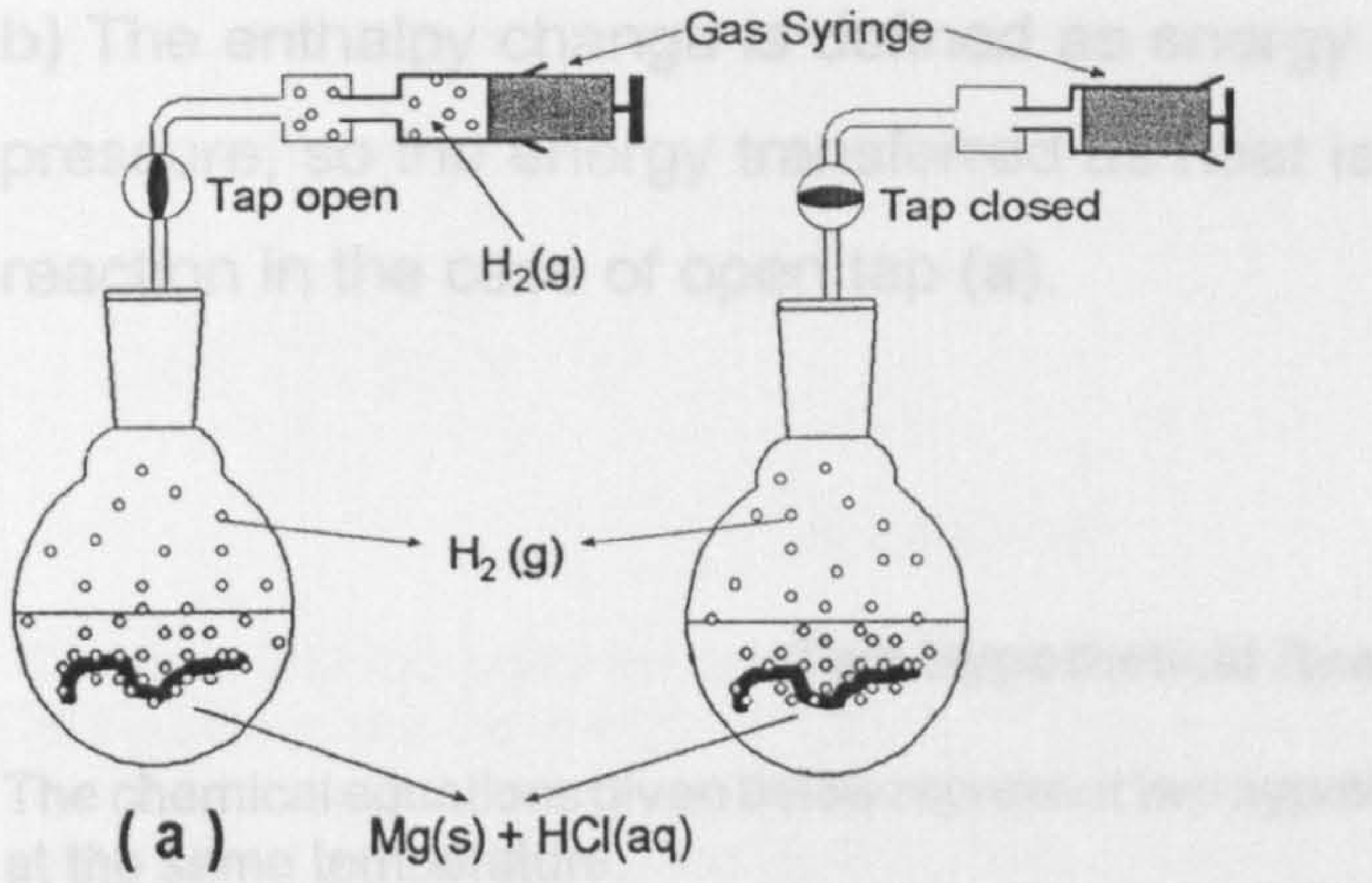
The expected answer is: For both sub-questions the answer is the same. The energy given out or gained in a reaction depends on the overall strengths of the bonds of molecules and/or compounds of the reactants and the products. If the overall strengths of the bonds are more than those of the products then energy is required to perform the reaction and it is called as an endothermic reaction. Alternatively if the situation is reversed it would be called an exothermic reaction. In other words, if weaker bonds are broken and stronger bonds are made then the system supplies energy as heat to the surroundings and such reactions are called exothermic. Conversely if stronger bonds are broken and weaker bonds are made the surroundings supply heat to the system and such reactions are called endothermic (Mapple, 1997; p.162).

Magnesium

Consider the reaction,

$$Mg(s) + 2\,HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta_rH^{\circ} = -\,463\ kJ\ mol^{-1}$$

taking place in each set of apparatus shown below.



In **a** the tap is open; in **b** the tap is closed. Equal amounts of reactants are used in each case.

Consider that the reactions are completed and the systems are cooled down to their initial temperature, and you are able to measure the heat given out to the surroundings by the reaction. On the basis of this information:

a) In which set of apparatus do you think most heat is given out to the surroundings? Explain your answer as carefully as you can.

b)In which set of apparatus does energy transferred as heat equal the reaction enthalpy?. Explain your answer as carefully as you can.

Magnesium probes students' understanding of enthalpy. The diagram represents both internal energy change, the heat released in tap closed balloon (**b**), and enthalpy change which is heat released in the tap open balloon (**a**) however enthalpy is the subject of the question.

<u>The idea being tested is</u>: Enthalpy change is the energy transferred as heat at a constant pressure.

<u>The expected answers are</u>:

a) The same reaction occurs in both apparatus and the same amount of energy is released but, the transfer form of the energy is different in two cases. The energy transferred to the surroundings as heat in balloon (**b**) is greater than in flask (**a**) because, in flask (**b**) the tap is closed and all the energy is released from system to surroundings as heat, but in flask (**a**) the tap is open and some of the energy released from the reaction is spent doing work by pushing back the syringe connected to the apparatus. Therefore, the amount of energy transferred as heat is less in the case of the open tap.

b) The enthalpy change is defined as energy transferred as heat at a constant pressure, so the energy transferred as heat is equal to the enthalpy change of reaction in the case of open tap (**a**).

Two Hypothetical Reactions

The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1	A + B → C + D	Exothermic
Reaction 2	E + F → G + H	Endothermic

a) On the basis of this information, can you compare the rate of these two reactions? If so, how? Explain your answer as carefully as you can.

b) What do you think about the spontaneity of these two reactions. Explain your answer as carefully as you can.

Two Hypothetical Reactions probes a common misunderstanding about the rates of the exothermic and endothermic reactions. It is designed to reveal whether undergraduate students hold the same misunderstanding that exothermic reactions occur faster than endothermic reactions as secondary school students. It is also tests the students' understanding of spontaneity.

The ideas being tested are:

a) The change in enthalpy can be a guide to stability of products and the reaction stability but gives no indication of the rate of a reaction.

b) Both endothermic and exothermic reactions can be spontaneous.

The expected answers are:

a) Thermodynamics quantities say nothing about the rate of a reaction, hence it is not possible to compare the rate of the reactions according to reaction enthalpy.

b) Both of these hypothetical reactions (exothermic and endothermic) can be spontaneous.

Ice Melting

Consider that there are two identical 1 L glass beakers containing 300 mL of water and 250 g of crushed ice in each. 1 mol NaCl is added to the first beaker and 1 mol KI is added to the second beaker. A certain time later, it was observed that the ice melted quickly in the beaker to which NaCl was added, whereas there was more ice in the beaker to which KI was added.

Using this information, decide which salt absorbs more heat when it dissolves in water. Explain your answer as carefully as you can.

The idea being tested is: Enthalpy is an extensive property which means that the enthalpy of a substance depends on the size of the sample.

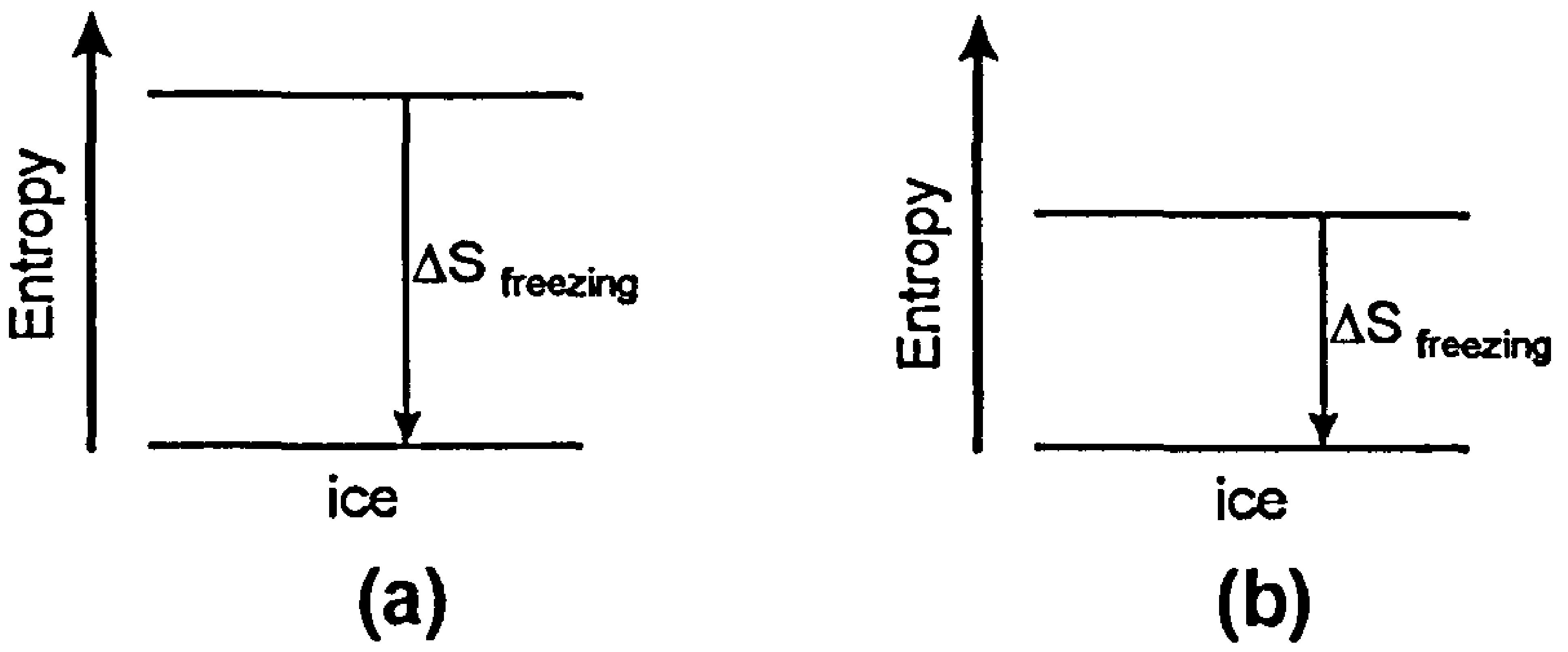
The expected answer is: When both salts dissolve, they absorb heat from the surroundings which is water in this case. The remaining ice in the beaker, to which KI was added, shows that the more heat absorbed from water during the dissollution of KI. This prevents the melting of ice in the water and this indicates that KI absorbed more heat from the surroundings than NaCl when dissolved. Both NaCl and KI added are 1 mol, but KI has more molecular mass than NaCl. This is another proof that KI should absorb more heat than NaCl during dissollution.

Entropy and Related Ideas

Four questions were posed, *Seawater, Mixing of Gases, Spontaneous Change* and *Carbon Dioxide and Propane,* to probe students' understanding of entropy and related ideas.

Seawater

Seawater contains different kinds of dissolved minerals, and therefore freezes at a lower temperature than pure water. The released energy is the same when seawater and pure water freeze. Two diagrams below show the entropy change of the freezing seawater and the pure water.



a) Decide which diagram represents the entropy change of the seawater when it freezes, and explain your answer as carefully as you can.

b) The entropy of freezing of pure water at 0 °C and 1 bar is:

$$H_2O(l) \rightarrow H_2O(s) \qquad \Delta S = -22.0 \text{ J K}^{-1}\text{mol}^{-1}$$

By using this piece of information, compare the magnitude of entropy change that happens in the surroundings when seawater freezes with the magnitude of entropy change that happens in the surroundings when pure water freezes at 0°C and 1 bar.

Explain your answer as carefully as you can.

This question probes students' understanding of entropy changes which happen in a system and its surroundings. When changes occur in a system these are nearly always accompanied by changes in the surroundings. The idea being tested has a practical application in daily life such as putting salt on icy roads.

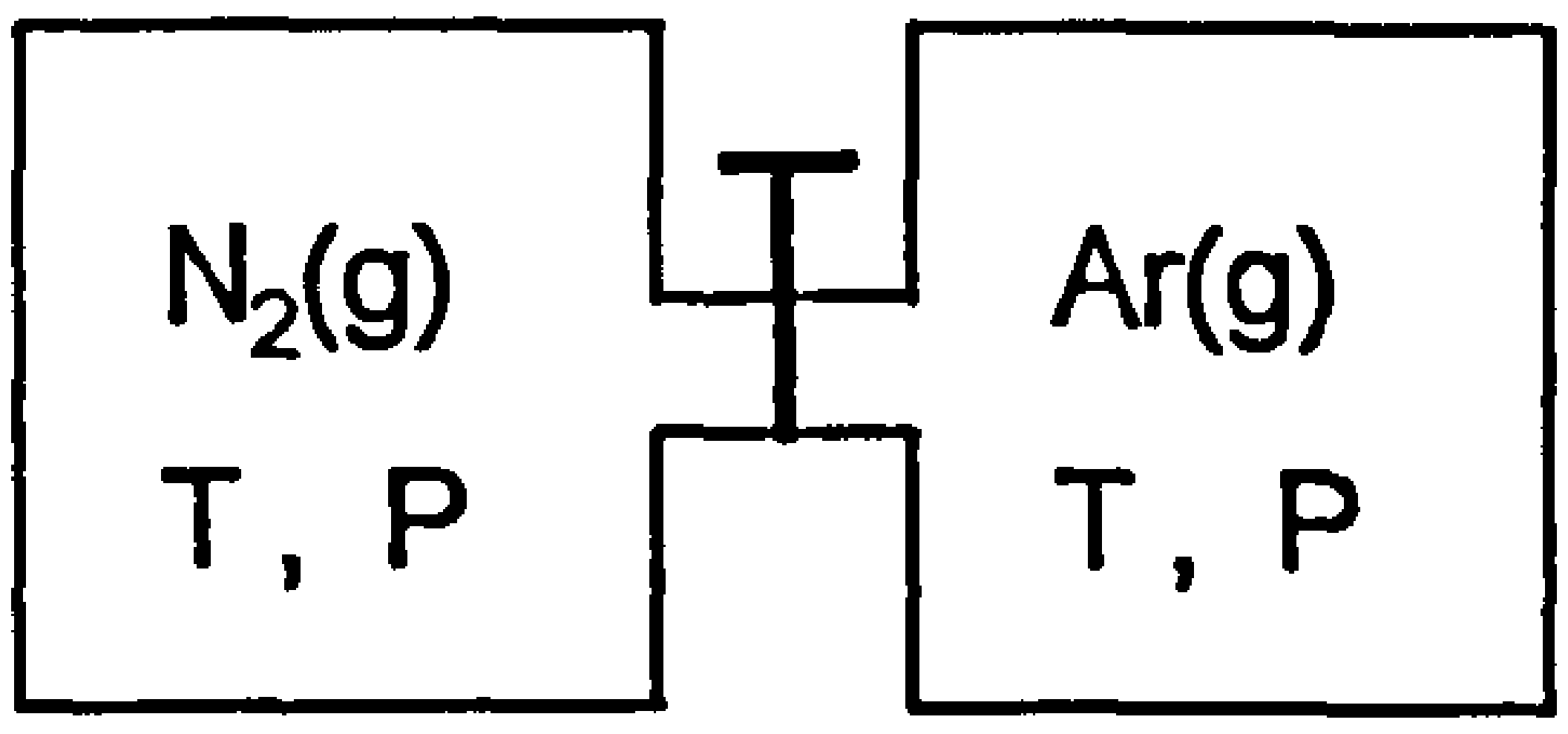
The idea being tested is: Any process that increases the number of particles in the system increases the number of microsystems and therefore increases the entropy of the system.

The expected answers are:

a) Diagram (**a**) because seawater contains a number of dissolved particles. It has more entropy than pure water. Here, it is assumed that ΔH and ΔS do not vary with temperature, although there is a small variation. When they freeze both produce pure ice and the energy released will be the same (as it is given in the question) as when molecules fit together to form a lattice in ice crystal. However, ΔS for the system will vary because the entropy of seawater is greater than the entropy of pure water because of the dissolved ions in it. There are more ways of arranging water molecules on the ions in the seawater than pure water molecules alone. Therefore, ΔS is more negative when seawater freezes.

b) When seawater freezes, the entropy change of the system is more negative than -22.0 J $K^{-1}mol^{-1}$ because of the reason as explained in (**a**). The changes in a system are accompanied by changes in the surroundings, hence the magnitude of the entropy changes in the surroundings when seawater freezes is greater than when pure water freezes. There is a more positive entropy change in the surroundings when seawater freezes.

Mixing of Gases



Imagine that two gases, nitrogen and argon, are placed in equal volume containers which are connected to each other by a tap. Their initial pressures are both P. The tap is opened and the two gases are allowed to mix at constant temperature. After the mixing, the entropy of the gases increases and their final total pressure stays P. Also, argon and nitrogen gases do not react with each other. *Using this information:*

a) Explain as carefully as you can why entropy increases when the gases mix.

b) Estimate how the enthalpy of the gases changes. Explain your answer as carefully as you can.

c) Estimate how the Gibbs energy of the gases changes. Explain your answer as carefully as you can.

This question concerns the changes in entropy, enthalpy and Gibbs energy that occur when gases are mixed. It tests the ideas from three different areas in each sub-question, but the main idea is entropy. The other sub-questions are posed to reveal how students apply the same process into different ideas.

The idea being tested is: Entropy is the measure of the number of ways that energy can be shared among particles. Entropy increases if the number of ways of distributing the available energy among the particles is increased, as well as the number of ways of arranging the particles in space.

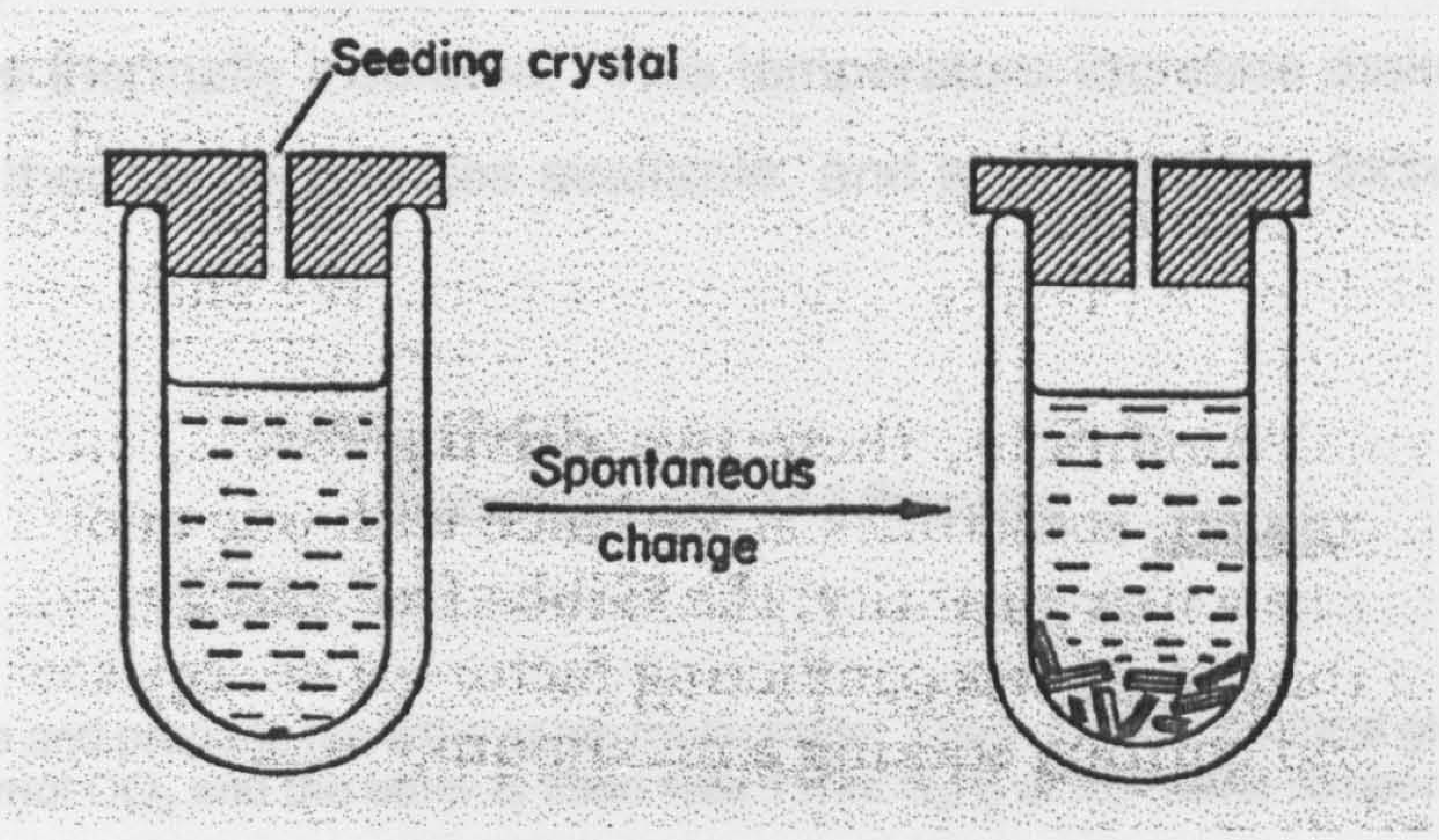
The expected answers are:

a) Entropy increases when gases mix because of the increase in the available space for the particles. Also, the number of ways of arranging the particles in space increases and this causes an increase in the number of possible microsystems. Hence, entropy increases when these two gases mix.

b) There is no change in the enthalpy of gases because the temperature of the system has been kept constant.

c) Since the mixing process occurs spontaneously Gibbs energy will be negative. All spontaneous processes are accompanied by a decrease in Gibbs energy.

Spontaneous Change



A hot saturated solution of sodium thiosulfate is allowed to cool slowly. If care has been taken to keep the materials clean and dust free , supercooling (*staying liquid below the temperature of the* freezing *point*) by several degrees is possible. The solution is then sealed in a thermally insulated flask. On dropping a tiny seeding crystal through a hole in the lid (see the figure) crystallization occurs spontaneously, with an apparent increase of organisation.

What do you think will happen to the entropy of the system when the crystals form? Explain your answer as carefully as you can.

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This question shows us that visual disorganisation and entropy are not synonymous ideas. The number of equivalent arrangements of microstates should be considered. If entropy is considered from the visual disorder point of view, it is not always possible to explain every situation. This question is an application of the Second Law of Thermodynamics to a problem. The picture has been taken from Warn (1988, p.61).

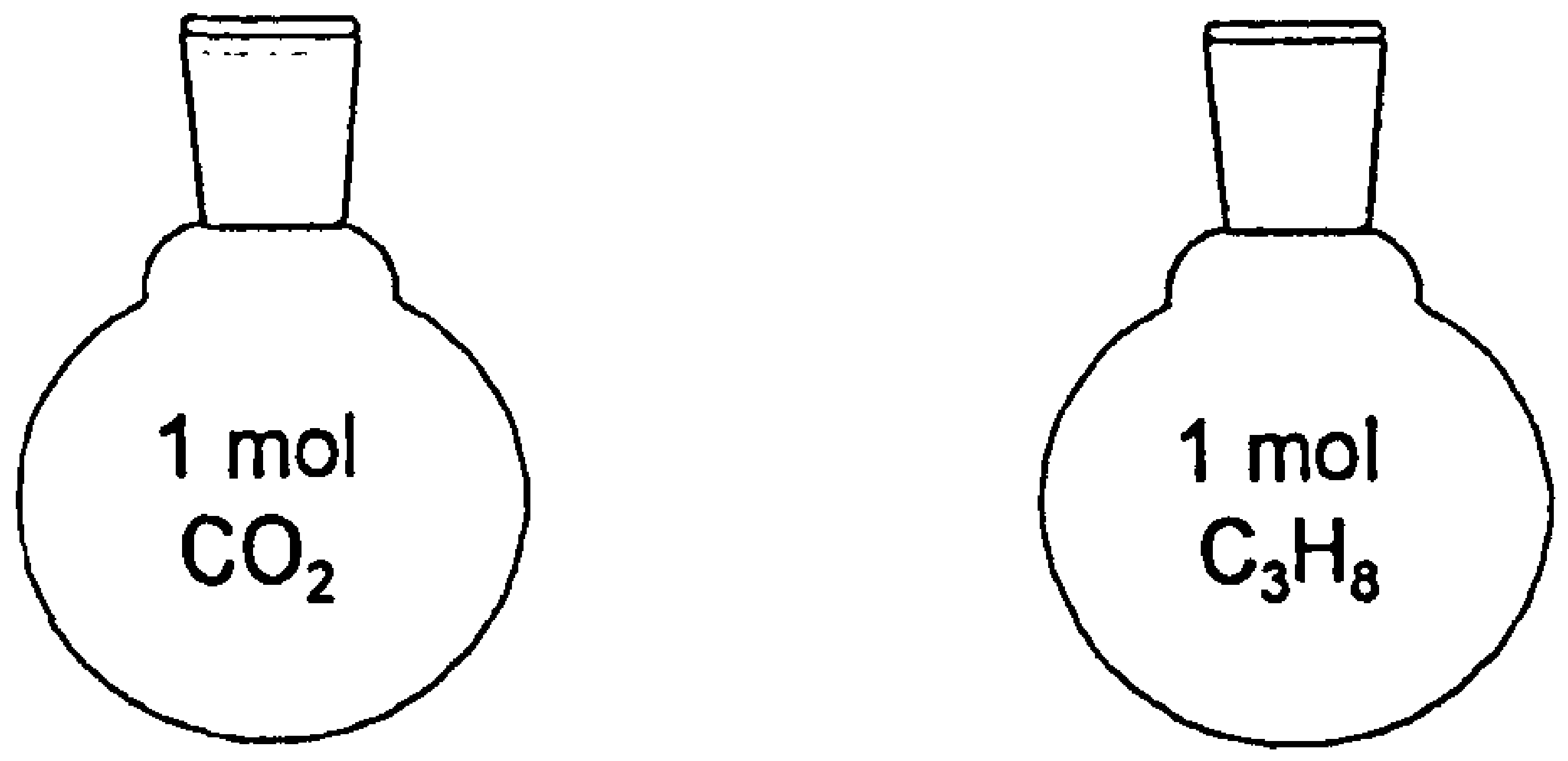
<u>The idea being tested is</u>: during a spontaneous change the entropy of the universe increases.

<u>The expected answer is</u>: Entropy of the system increases when crystallisation occurs since it is a spontaneous process. The second law of thermodynamics tells us that the entropy of the universe increases during a spontaneous process. Two competing factors should be considered. On one hand, there is an apparent increase of organisation when crystallisation occurs but on

the other hand, the temperature of the system increases during freezing because of the energy released due to the formation of new bonds in the ice crystals since the system is thermally insulated. This temperature increase makes a greater spectrum of thermal microstates available, and so the entropy increases in this process.

Carbon Dioxide and Propane

Carbon dioxide and propane have the same molar mass. There are two identical glass flasks. One is filled with 1 mol CO_2 and the other is filled with 1 mol C_3H_8 at the same temperature as shown below.



Which gas do you think has the greater entropy? Explain your answer as carefully as you can.

This question tests one of the fundamental ideas which is the importance of the number of atoms and the molecules in determination of entropy.

The idea being tested is: Substances have higher entropies if they contain heavier atoms and a larger number of atoms.

The expected answer is: Since the propane (C_3H_8) gas has more atoms than carbon dioxide (CO_2) and they are more branched out in propane, propane has greater entropy than carbon dioxide. The branching causes an increase in number of possible ways in which energy can be shared amongst the atoms.

Gibbs Energy and related Ideas

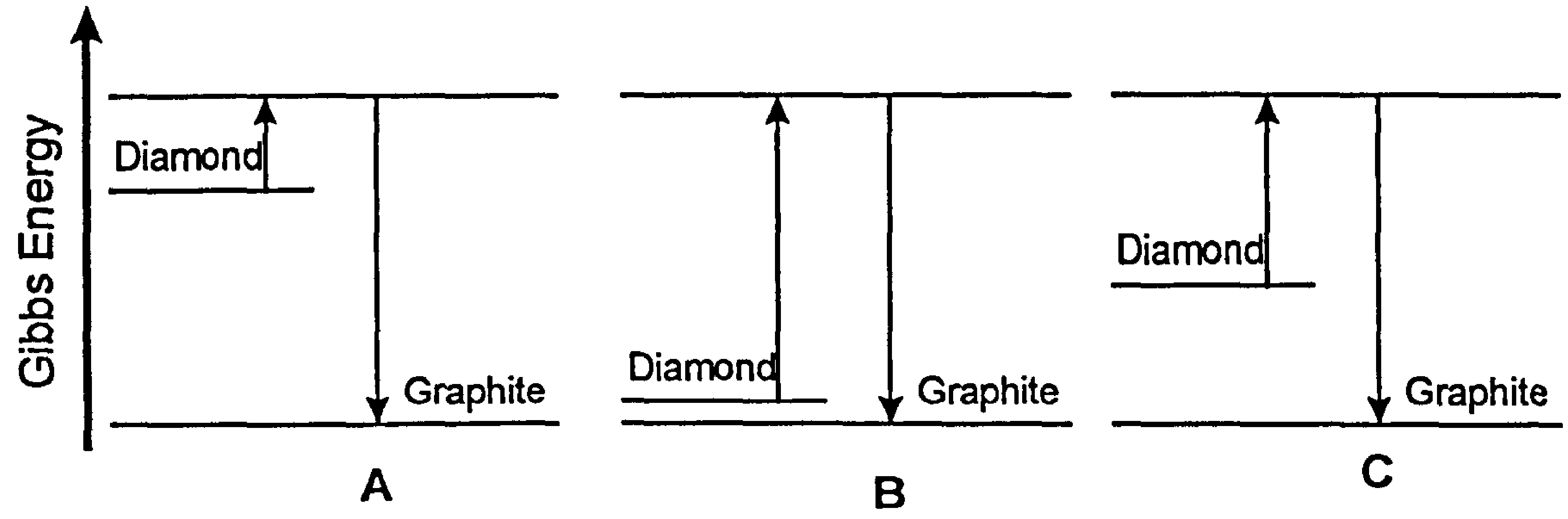
Three questions were posed, *Transformation of Diamond to Graphite, Two spontaneous Reactions* and *Gibbs Energy, to* probe students' understanding of Gibbs energy.

Transformation of Diamond to Graphite

The transformation of diamond to graphite is a very slow process which cannot be observed over the duration of human life. The chemical reaction for the transformation process can be given as:

$$C_{(Diamond,\ s)} \rightarrow C_{(Graphite,\ s)}$$

The three diagrams below represent the Gibbs energy changes for the process. Which of these diagrams do you think best represents Gibbs energy change of the transformation of diamond to graphite? Explain your answer as carefully as you can.



In this question the crucial point is the students' explanation of their particular response. It was intended to test whether students relate the magnitude of reaction Gibbs energy with the reaction rate.

The idea being tested is: The magnitude of $\Delta_r G$ indicates how far the reaction is from equilibrium at a given composition but it does not give any information about the rate of a reaction.

<u>*The expected answer is*</u>: Any of the above diagrams would be correct since they are not supplied with numerical data. ΔG is a thermodynamic value and gives information about the equilibrium but not about the rate of reaction. There are reactions that have a very negative ΔG value but occur very slowly and also some reactions that occur very quickly but have very small negative ΔG value. So, ΔG is not a criteria for determining the rate of reaction.

Two Spontaneous Reactions

Two spontaneous reactions are shown below. Their standard Gibbs energies are also given.

1 - $CO(g) + 2\,H_2(g) \rightarrow CH_3OH(l)$ $\Delta_rG^\circ = -2.9 \times 10^4\ J\ mol^{-1}$

2 - $4\,Fe(s) + 3\,O_2(g) \rightarrow 2\,Fe_2O_3(s)$ $\Delta_rG^\circ = -1.49 \times 10^6\ J\ mol^{-1}$

a) Can these data be used to say anything about the relative rates of these reactions? If so why? Explain your answer as carefully as you can.

b) In your opinion, which of the above reactions would <u>most fully go towards completion</u>? Explain your answer as carefully as you can.

<u>*The ideas being tested are*</u>:

a) Thermodynamic quantities tell us nothing about the rate of the reaction.

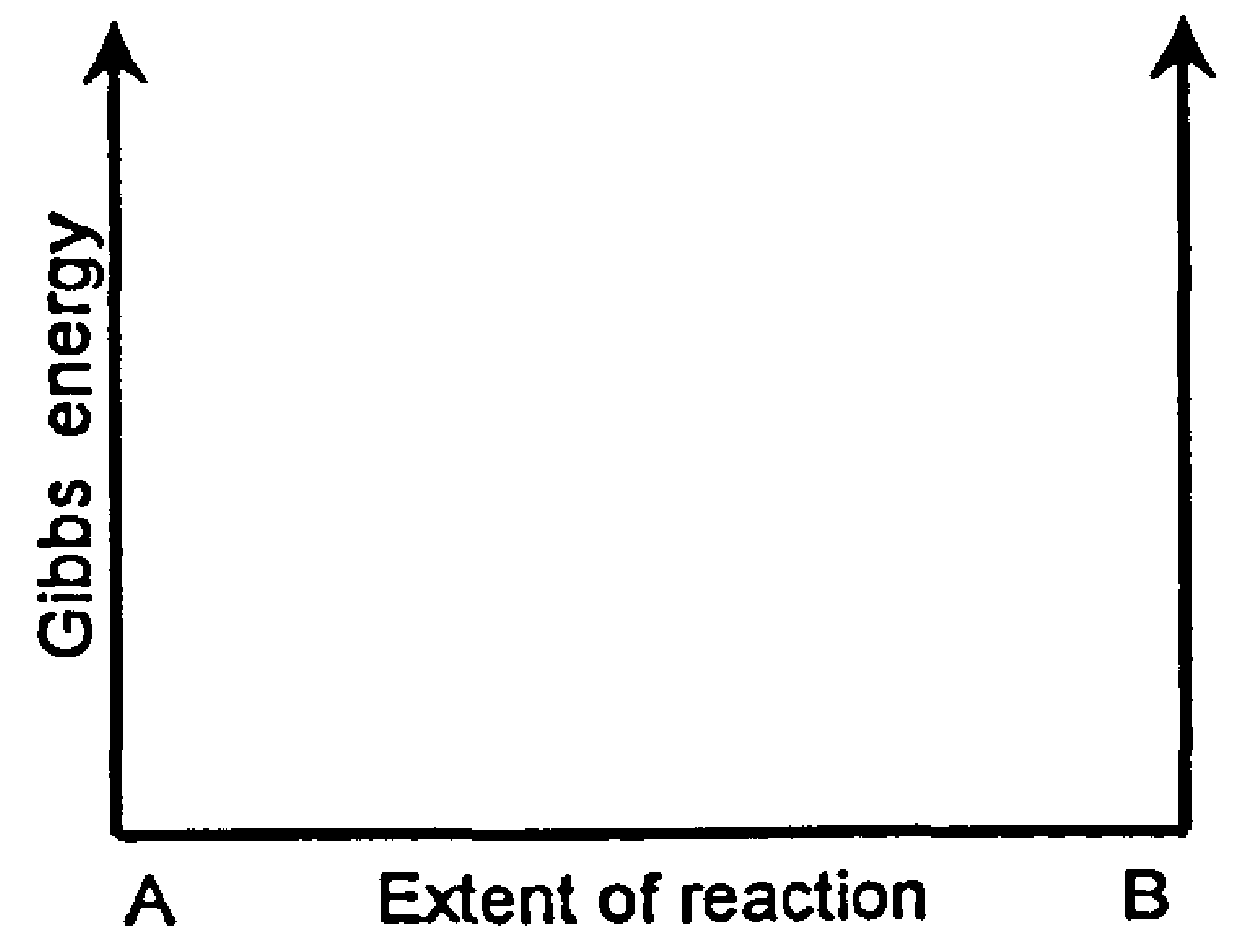
b) A more negative value of Δ_rG indicates the greater the probability that the reaction will occurs, and also the more negative value of Δ_rG^0, the larger positive value of the reaction equilibrium constant, K.

<u>*The expected answers are*</u>:

a) This data cannot be used to make an estimation about the relative rates of the reactions because thermodynamic quantities cannot be used to make an estimation about the kinetics of a reaction.

b) The second reaction would go towards full completion. $\Delta_r G^0$ value is more negative which indicates the bigger value of K meaning a bigger concentration for the products than the reactants in the system. Thus, the second reaction goes towards full completion.

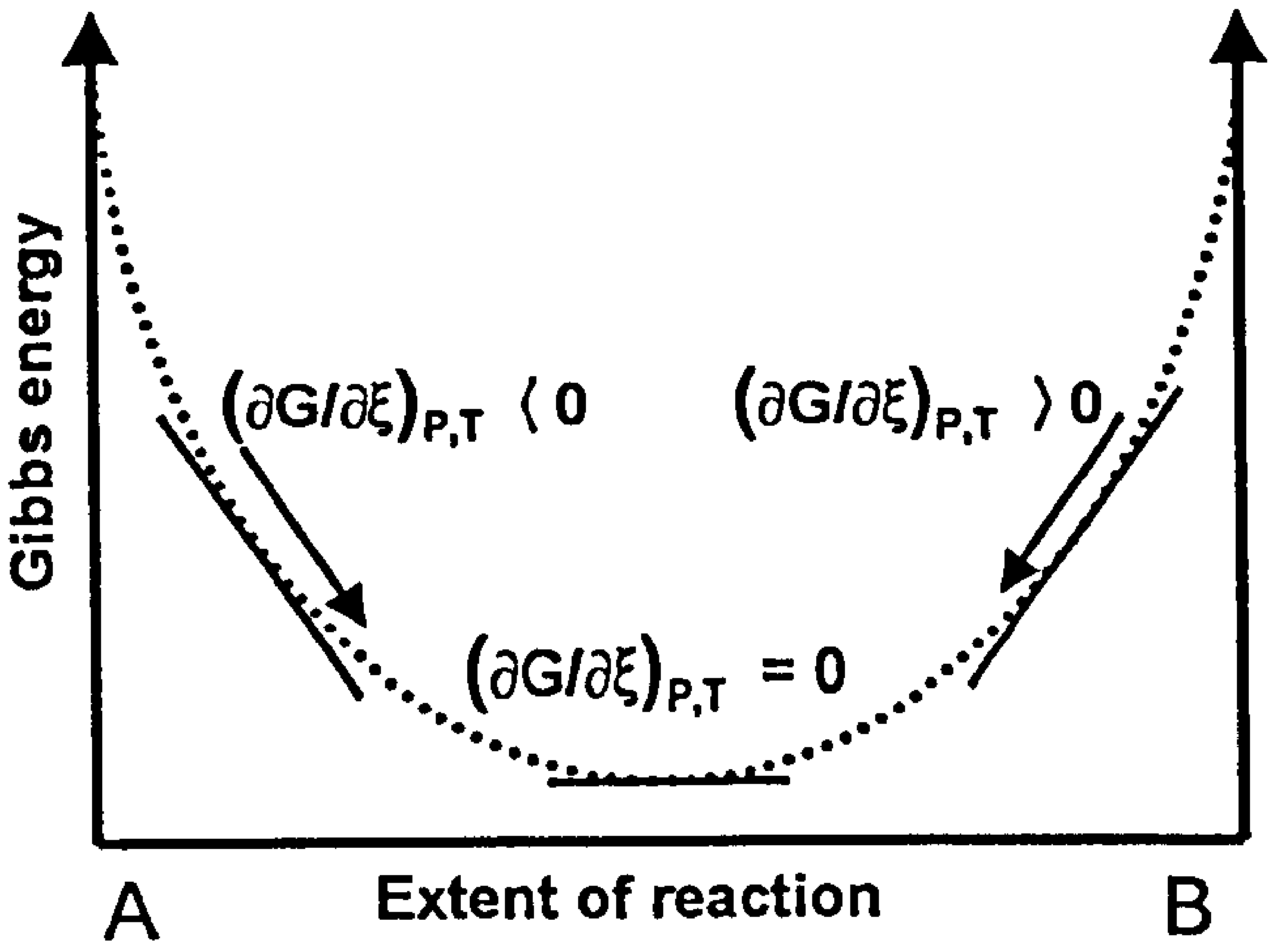
Gibbs Energy



Draw a graph of Gibbs energy versus extent of reaction A → B on the diagram is shown here. Discuss and interpret the graph as carefully as you can.

The idea being tested is: The Gibbs energy change tends to become zero when the system approaches equilibrium and is zero at equilibrium.

The expected answer is: The following graph was expected to be drawn. As indicated on the graph, chemical reactions spontaneously approach the equilibrium state from both directions; A → B or B → A. The equilibrium state always has a lower Gibbs energy than that of either reactants or products. As the reaction approaches the equilibrium the Gibbs energy change decreases and at the equilibrium state the change in Gibbs energy becomes zero. At equilibrium,



the entropy of the universe attains a maximum level compared to minimum Gibbs energy.

Appendix 9

The survey sheet

What do you think makes hard for you to understand chemical ideas in physical chemistry? Please discuss with your friends in group and write them down.

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! If you have more to say please continue on the back of the sheet please

What do you think could be done to help you understand these ideas better? Please discuss with your friends in group and write them down.

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! If you have more to say please continue on the back of the sheet please

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