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Prospective Chemistry Teachers' Conceptions of Chemical Thermodynamics and Kinetics

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This study aimed at identifying specifically prospective chemistry teachers' difficulties in determining the differences between the concepts of chemical thermodynamics and kinetics. Data were collected from 67 prospective chemistry teachers at Kâzım Karabekir Education Faculty of Atatürk University in Turkey during 2005-2006 academic year. Data collection performed through two different instruments. In order to determine prospective teachers' difficulties in determining the differences between the concepts of chemical thermodynamics and kinetics, a diagnostic test composed of five open-ended questions was specifically developed for this study. Thirteen participants (out of 67) were also interviewed in order to gather more information about the written responses. The analysis of results showed six major misconceptions about the difference between the concepts of chemical thermodynamics and kinetics indicating that the prospective chemistry teachers attempted to interpret the kinetics of several phenomena by using thermodynamics data. The findings reported here may contribute to understanding of undergraduates' difficulties and can be utilized in research that develops teaching strategies to overcome such difficulties.

Keywords: Chemical kinetics, chemical thermodynamics, prospective chemistry teachers, misconceptions, teacher training.

INTRODUCTION

Quantitative studies of chemical reactions tend to fall into one of two groups. There are those relating to the actual occurrence of the reaction, regardless of how quickly or how slowly it takes place. These may measure such quantities as the standard enthalpy change or the standard Gibbs free energy change of the reaction. These are the subject matter of *chemical thermodynamics*. The second group of studies relates to the speed with which a chemical reaction occurs and, unlike the first group, it uses time as a variable. The subject matter of this second group of studies is called *chemical kinetics*. The inter-relationship of chemical thermodynamics and chemical kinetics is an issue of some interest and complexity. However, for chemical reactions that are readily amendable to kinetic study, the reactant and product species are usually all in the same homogeneous phase. Regardless of whether this is the gas phase or solution, thermodynamics tells us that only a certain extent of reaction would offend the Second Law of Thermodynamics. On the other hand, there are no laws stipulating how quickly this extent of reaction is approached. The reaction may well be so slow that this is unobservable (Logan, 1996).

Almost every argument and explanation in chemistry boils down to a consideration of some aspect of energy. Energy determines what molecules may form, what reactions may occur, how fast they may occur, and also in which direction a reaction has tendency to occur. Energy is central to chemistry, yet it is difficult to give a satisfactory account of what energy is (Atkins, 1996).

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State of the literature

- Students' ideas about thermodynamics concepts such as heat, temperature, equilibrium are extensively studied and misconceptions are well documented at elementary, secondary and tertiary level.
- Students' ideas about chemical kinetics are rarely studied. The studies about chemical kinetics mostly do not go beyond a content analysis of the domain except few studies focused students' understanding of the concept.
- Studies on thermodynamics and kinetics are not focused on relationship and differences between thermodynamics and kinetics.

Contribution of this paper to the literature

- This study suggests that undergraduates' have learning difficulties in differentiating thermodynamic data (i.e. solubility, equilibrium constant, equilibrium, Gibbs free energy, enthalpy) and kinetic data (i.e. dissolution rate, equilibrium constant, reaction rate).
- Undergraduates use thermodynamic data to explain kinetic phenomena or vice versa.
- Most students have superficial understanding of thermodynamics and kinetics. Their understandings do not go beyond algorithmic problem solving. There is a lack of conceptual understanding of concepts associated with thermodynamics and kinetics.

Thermodynamics is concerned with the study of the transformation of energy, and in particular the transformation of energy from heat into work and vice versa. That concern might seem remote from chemistry. Indeed, thermodynamics was developed during the nineteenth century by physicists and engineers interested in the efficiency of steam engines. Thermodynamics, which is a science of the macroscopic world, not only deals with the energy output of chemical reactions but it helps to answer questions that lie right at the heart of everyday chemistry, such as why reactions reach equilibrium, what their composition is at equilibrium, and how reactions in electrochemical (and biological) cells can be used to generate electricity (Atkins, 1996; Warn, 1988). On the other hand, 'chemical kinetics is concerned with the rates of chemical reactions; how rapidly reactants are consumed and products formed, how the rate responds to changes in the identification of the steps by which the reaction takes place' (Atkins, 1996; p.233). Understanding reaction kinetics is important for two aims. The first is the practical importance of being able to predict how quickly a reaction mixture approaches equilibrium. The second reason lies behind understanding the mechanism of a reaction (Atkins, 1996).

Despite the importance of chemical thermodynamics and kinetics as the foundation of chemistry, most students pass introductory courses with several misconceptions about these subjects (Banerjee, 1995; Beal, 1994; Cakmakci, Leach, & Donelly, 2006; Carson and Watson, 1999; Carson and Watson, 2002; Fuchs, 1987; Granville, 1985; Johnstone, MacDonald, & Webb, 1977; Ochs, 1996; Selepe and Bradley, 1997; Sozbilir, 2001; Sozbilir, 2002; Sozbilir, 2003a; Sozbilir & Bennett, 2006; Sozbilir & Bennett, 2007; Thomas, 1997). Physical chemistry courses, where students tackle more advanced ideas of thermodynamics and kinetics are perceived by many students to be one of their most difficult courses (Sozbilir, 2004).

Research on learning difficulties associated with thermodynamics from elementary to undergraduate level is well documented. These studies have characterized student conceptions of heat and temperature (e.g., Brook, Briggs, Bell, & Driver, 1984; Erickson, 1979; 1980; 1985; Grayson, Harrison, & Treagust, 1995; Harrison, Grayson, & Treagust, 1999; Lewis & Linn, 1994; Linn & Songer, 1991), energy (e.g., Duit, 1987; Goedhart & Kaper, 2002), phase changes (e.g., Azizoğlu, Alkan, & Geban, 2006; Osborne & Cosgrove, 1983), equilibrium (e.g., Banerjee, 1995; MacDonald, 1990; Thomas, 1997, Van Driel & Gräber, 2002), and the second law of thermodynamics (e.g., Duit & Kesidou, 1988; Kesidou & Duit, 1993). Reviews covering students' conceptual difficulties about several thermodynamic ideas such as heat and temperature (Sozbilir, 2003b), chemical equilibrium (Van Driel & Gräber, 2002), chemical energetics and chemical thermodynamics (Goedhart & Kaper, 2002) and entropy (Sozbilir, 2003a) suggest that students have significant learning difficulties in thermodynamics. However, studies focused on students' understanding of chemical kinetics are rare compared to chemical thermodynamics (Cakmakci, Leach, & Donnelly, 2006; Justi, 2002). Chemical kinetics, one of the most fundamental concepts in chemistry, is regularly taught in both school and university courses (Justi, 2002). Nevertheless, chemical kinetics has been regarded as difficult for students in school (Cachapuz & Maskill, 1987; De Vos & Verdonk, 1986; Van Driel, 2002) and university courses (Cakmakci, Leach, & Donnelly, 2006; Lynch, 1997). A comprehensive review of teaching and learning chemical kinetics (Justi, 2002) suggests research on chemical kinetics usually does not go beyond a content analysis of the domain (e.g., Lambert, 1998; Logan, 1984), teachers/lecturers' personal experience on their students' difficulties (e.g., Copper & Koubek, 1999) and that students' ideas of reaction rates were quoted in the literature in the context of research into

students' views of chemical equilibrium (Quilez & Solaz, 1995) and thermodynamics. Justi and Gilbert's study (1999) is an extension of this field in that they investigated models expressed by Brazilian teachers and students in the light of historical consensus models in chemical kinetics. Most recently, Cakmakci, Leach, & Donnelly (2006) determined high school students' and undergraduates' ideas related to reaction rate and its relationship with concentration or pressure. Their results suggested that school students tended to use macroscopic modelling rather than particulate and/or mathematical modelling; undergraduates were more likely to make explanation based upon theoretical models. Nevertheless, students at both levels had conceptual difficulties in making transformation within and across different theoretical models indicating that they were not able to use scientifically acceptable concepts of reaction rate across context and displayed misconceptions.

Purpose and Research Question

Although several studies cited above investigated students' understanding/misunderstanding of ideas related to chemical thermodynamics and kinetics, no systematic study focused on identifying students' conceptions of the differences between the concepts of chemical thermodynamics and chemical kinetics. Thermodynamics concepts such as heat, temperature, equilibrium are widely studied both at elementary and secondary levels and students' alternative concepts are well documented. However, there is a shortage of research to provide guidance on how to improve the teaching of chemical thermodynamics and kinetics at the tertiary level. The present study may provide some guidance for teachers by identifying prospective chemistry teachers' difficulties in determining the differences between the chemical thermodynamics and kinetics and providing recommendations on how to address these difficulties. Consequently, the research question investigated in this study was:

- *What are Turkish chemistry undergraduates' misconceptions in determining the differences between the concepts of chemical thermodynamics and kinetics?*

METHODOLOGY

Sampling

The present study employed a descriptive approach in order to achieve the aim described above. Data was collected from sixty-seven prospective chemistry teachers. Thirty-seven of them were enrolled to *Master without Thesis Combined with Bachelors Degree* and thirty to the *Master without Thesis* at Kâzım Karabekir Education Faculty of Atatürk University in Turkey during 2004-2005 academic year. Participation in the study was voluntarily. Atatürk University provides a master's programme without a thesis, similar to Post Graduate Certificate in Education (PGCE) in UK which is one year long (two semesters) postgraduate teacher training courses, qualifying chemistry graduates for teaching in secondary schools (students aged 14-17) together with regular chemistry teacher training which is a five year program, entitled "Master without Thesis Combined with Bachelors Degree", qualifying chemistry teachers for teaching in secondary schools (students aged 14-17). Graduates who have a BSc in chemistry could enrol in the one and half year (three semesters) master without thesis program if they want to be chemistry teachers in secondary schools. On the other hand, the "Master without Thesis combined with Bachelors" degree accepts students through a centralized nationwide examination which is held every year and is administered by the Student Selection and Placement Centre (ÖSYM). Candidates gain access to institutions of higher education based on their composite scores consisting of the scores on the selection examination as well as their high school grade point averages.

Data Collection Tools

Two different instruments were used to collect data. In order to determine prospective teachers' misconceptions in determining the differences between the chemical thermodynamics and kinetics a diagnostic test composed of five open-ended questions was specifically developed to test prospective teachers' knowledge of differentiating the concepts of chemical

Table1. Misconceptions identified from assessment of undergraduates' written responses to diagnostic test

No	Undergraduates' misconceptions as identified by the diagnostic test	Undergraduate Adherents (N=67)
		f(%)
1	Dissolving rate of a gas in water decreases with increasing temperature	53(79)
2	The larger equilibrium constant, the faster a reaction occurs	35(52)
3	The smaller equilibrium constant, the faster a reaction occurs	14(21)
4	The rate of forward reaction decreases with increasing temperature for an exothermic reaction	38(57)
5	The larger negative free energy change a reaction has the faster it occurs	30(45)
6	Exothermic reactions occur faster or endothermic reactions occur faster	28(42)

thermodynamics and kinetics (see Appendix 1). The researchers" previous experiences in teaching helped them to identify the undergraduates' difficulties in differentiating thermodynamics and kinetics. In order to maintain the content validity of the test, it was given to four lecturers who were asked to assess the content, ideas tested and the wording of the questions. All questions were piloted with third year undergraduates taking physical chemistry course. Undergraduates' views about the content and wording of the questions were taken immediately after they completed the test and required modifications were made prior to the administration of the test.

The test was administered under normal class conditions without previous warning two months prior to students' graduation. Respondents were given a normal class period of 50 minutes to complete the test. Students were informed that the results of the test would be used for research purposes and would be kept confidential.

Based on the initial coding of the responses, prevalent misconceptions were identified. These misconceptions articulated how these prospective teachers differentiate the concepts of chemical thermodynamics and kinetics, but did not provide in-dept explanations of their personal views. To address this limitation, thirteen prospective teachers were interviewed in order to clarify their written responses and to further probe conceptual understandings of the questions asked in the test. Interviewees were selected on the basis of their responses on the written test. If a student's written test response demonstrated a misconception without providing an in-depth or clear explanation of his or her response, we requested interviews with them. The interviews lasted approximately 20–30 minutes. All the interviews were audio recorded (with the interviewees' consent) and then transcribed for analysis. The interviews did not go into great detail; instead they were used to elucidate the students' misconceptions based on their written responses.

Data Analysis

Students' responses to the diagnostic questions were analyzed, misconceptions were determined, and percentages were calculated for the responses. Misconceptions held by over 20% of the subjects are reported here. Interview data were not subjected to a rigorous analysis but rather was used to support the diagnostic test results. Because the interviews were conducted in Turkish, the quotes reported in this paper are translations of the researchers' questions and the students' responses.

RESULTS

Results of analysis of all participants' responses are presented and discussed together as the study did not aim to determine the differences between the groups. However, distribution of the responses was almost homogeneous. Table 1 shows the misconceptions identified by the written responses to diagnostic test. The results are presented in the order of questions in the test provided in Appendix 1.

The students' written responses on the first question showed that 79% of the prospective chemistry teachers held the view that the dissolving rate of a gas in water decreases with increasing temperature. A further analysis of participants' responses to the interview questions indicated that this misconception stems from the idea in which the students tried to make a connection between the effect temperature on dissolving rate of a gas and its solubility. The students holding this idea believed that the higher the solubility of a gas, the faster its' dissolving rate or the lower the solubility of a gas, the slower its dissolving rate. To be clearer, they considered that there is proportionality between solubility and dissolving rate of a gas, as indicated in the written responses given below:

"The solubility of gases in water is exothermic. So, when temperature is increased its solubility decreases, causing a decrease in its dissolving rate"

"…with the increasing temperature, the velocity of gas molecules increases. For this reason its solubility decreases, and its dissolving rate also decreases as depends on solubility"

"X (g) ⇆ X (aq) + heat, *according to this, increasing temperature shifts the equilibrium position to the left. This means a decrease in solubility. Because of this, the dissolving rate also decrease"*

As can be seen from the above quotations, the prospective teachers were able to correctly state the effect of temperature on solubility of a gas in water, but they failed to explain its effect on dissolving rate of the gas. One possible explanation of this misconception could be that the students regarded enthalpy change as a predictor of the effect of temperature on dissolving rate, as reported in a previous study by Pinarbasi, Canpolat, Bayrakçeken, & Geban (2006) who showed that students considered that dissolving rate is dependent on whether the solution process is exothermic or endothermic. For example students reasoned that in an exothermic dissolution process, dissolving rate decreases with increasing temperature or vice versa. The below dialogue is taken from the interviews exemplifies this view:

R1: …you say that with increasing temperature the dissolution rate decreases, could you give me some more information why?

I: Because the dissolution is exothermic... [long silence]

R: But the dissolving rate was discussed in class

I: Yes, sure. I mean that because it is exothermic if we increase temperature dissolving rate decreases

R: How have you come to this conclusion? Please, could you be a bit clearer?

I: I know that increasing temperature decreases solubility of a gas, so this causes a decrease in dissolving rate

R: What could be said about the dissolving rate in the case of a decrease in temperature?

I: Then, as solubility increases, it increases

In short, the above discussion indicates that the students tended to explain the effect of temperature on dissolving rate in terms of the effect of temperature on solubility.

There were two misconceptions identified from the analysis of prospective chemistry teachers' responses to the second question. The first one which was held by almost half of the prospective teachers (52%) is that for a reversible reaction, the larger the equilibrium constant, the faster it occurs. The second misconception was the reverse of the first one and was held by 21% of the students. For a reversible reaction, the smaller equilibrium constant, the faster the reaction occurs. The responses relating to this question indicated that prospective teachers tried to compare the rates of two reactions with different equilibrium constants, by comparing the values of equilibrium constants. The respondents with the first misconception stated that the larger equilibrium constant a reaction has, the more the reaction proceeds towards products and this means the reaction occurs faster, as can be seen in the excerpts taken from the written responses:

"The first one with larger equilibrium constant occurs faster, because compared to the second one, here the products are more favoured. This means it is faster."

"10-5 > 10-10, the first reaction is faster because the ratio of formation of the product is higher."

The preceding quotations explicitly show that prospective teachers considered the values of equilibrium constant as a determining factor in predicting the rates of the reactions. In fact, they correctly interpreted the equilibrium constant qualitatively that if the value of the equilibrium constant is large, the products are favoured at equilibrium. However, the problem is that they attempted to use equilibrium constant to predict the rate of reactions. This mistaken interpretation is apparent in interview quoted below:

R: Why do you think that the first reaction is faster?

I: Its equilibrium constant is larger.

R: What does that mean? Please be clearer.

I: If a reaction has a larger equilibrium constant, the products are more favoured.

R: What about the reaction rate?

I: Well, I mean that if the products are more favoured, the reaction takes place faster.

In a previous study by Banerjee (1995), which discussed the conceptual difficulties of undergraduate students regarding chemical equilibrium and thermodynamics, a similar misconception was reported: "a large value of equilibrium constant implies a very fast reaction". Canpolat, Pinarbasi, Bayrakçeken, & Geban (2006) and Wheeler & Kass (1978) reported similar results that students fail to distinguish between the rate of a reaction (kinetics) and the extent of a reaction (equilibrium/thermodynamics).

In contrast to the preceding misconception, the second misconception identified from the responses to the second question was that a reaction with lower equilibrium constant occurs faster. The reasoning behind this misconception was that if the equilibrium constant is small, there are fewer products and this take less time. One of the quotations from the written responses exemplifies this view:

"The second reaction has smaller equilibrium constant. Thus, it occurs faster because, less product forms in this reaction."

Again, the respondent correctly interpreted the relationship between the value of equilibrium constant and the amount of product formed. But similar to the explanations made about the misconception, the students mistakenly used equilibrium information to compare the rates of reactions. The following dialogue taken from interview demonstrates respondent's reasoning:

I: The second one is faster.

R: Why do you think so?

I: Its equilibrium constant is smaller than that of the first one, so the amount of product forming will be fewer. Fewer product means less time.

From all the findings revealed by question two, it could be concluded that the students believed that there was a direct relationship between equilibrium constant and reaction rate.

[1] R and I stand for the researcher and the interviewee respectively.

Analysis of the prospective teachers' responses to the third question revealed that 57% of them think that the rate of a forward reaction decreases with increasing temperature for an exothermic reaction. The respondents indicated that they first determined the shift in equilibrium when temperature is increased according to LeChatelier's Principle. Of course, as expected, they reasoned correctly that as temperature increases the equilibrium of an exothermic reaction is expected to shift to the reactant side. In order for the equilibrium to do this, the forward reaction rate (formation rate of SO_3) should reduce. The following written responses reflect this view:

"The fact that with increasing temperature the equilibrium position shifts to the left means a decrease in forward reaction rate."

"The equilibrium position shifts to the left and the amount of SO3 decreases. This indicates that the formation rate of SO3 decreases."

In the following the quotation from the interviews also reflects the same type of reasoning:

…

I: There is a decrease in the formation rate of SO3.

R: Why do you think so?

I: Because, the equilibrium position shifts to the left

R: What do you exactly mean?

I: When the equilibrium favours the reactants, the amount of SO3 decreases. In orderfor SO3 to decrease, its formation rate should decrease.

The above findings are in good agreement with those reported by Banerjee (1991) in which students reasoned that when the temperature is increased in an exothermic reaction, the rate of the forward reaction decreases. Banerjee (1991) suggested that this misconception largely originates from the wrong or overuse of the LeChatelier's Principle to predict rate and extent of a reaction although the LeChatelier's Principle could only be used to predict the direction of a reaction shift (direction of net change).

Responses to the fourth question revealed the misconception that the larger free energy change a reaction has, the faster it occurs. Forty-five percent (45%) of the prospective teachers held this misconception and believed that an increase in the negative value of free energy change increases the tendency of reaction to occur [*which is correct*], which in turn makes the reaction faster [*which is incorrect*]. The same reasoning is evident in the following written responses.

"The second one is faster, because its ΔG value is negatively larger."

"According to their ΔG values, the tendency of the second reaction to occur is larger, this means it is faster."

"Because more energy is released, the second one is faster."

From the above written responses, it is clear that many students believed that there is a direct relation between the value of ΔG and the rate of a reaction, which is also indicated in the following excerpt from the interviews:

…

I: The second one is faster.

R: Why?

I: Because its ΔG value is negatively larger, its tendency to occur is also larger. This makes it faster.

Johnstone, MacDonald, & Webb (1977) reported students' had difficulties similar to already indicated. They stated that there appeared to be a tendency for pupils to relate the magnitude of the free energy change to the rate of reaction. They reported that 25% of the students considered that a large negative free energy change in a reaction would occur rapidly. The authors suggested that one of possible reason students hold this misconception that students probably draw an analogy from the macro physical world where the further things fall, the faster they go, or even the more energy provided, the higher the velocity.

A few students tried to compare the rates of the reactions in terms of the relation between ΔG and equilibrium constant (K_p). This idea can be seen in the following written response:

"ΔG = - RT lnKp

- 10 = - RT lnKp(1)

- 100 = - RT lnKp(2)

because Kp(2) > Kp(1), the second reaction is faster"

In the light of this reasoning, it is not surprising that prospective teachers hold the idea that "large values of equilibrium constant imply a very fast reaction", as identified in question two.

The responses given to the last question showed that 42% of the respondents argued that exothermic reactions occur faster.

"The first reaction is an exothermic reaction. There is no need for energy to this reaction to occur 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."

As seen from the above quotation, the prospective teacher distinguishes two types of reactions: those that require energy –for activation or otherwise- and those that do not. Those that require energy are called endothermic by the student. In this case combustion

would be endothermic, as a burning match is needed to start it. It is clear here that the student confuses activation energy and reaction enthalpy and uses these concepts interchangeably. In addition, the student approaches the question in terms of stability. As energy is given out in exothermic reactions, products are more stable than the reactants. The student may think that this energy release may increase the reaction rate and therefore exothermic reactions would be faster. This indicates that prospective teachers confused the rate of a reaction with the spontaneous occurrence of a reaction. 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 rate of a reaction is the concern of kinetics while enthalpy change is the subject of thermodynamics. In other words, students confuse thermodynamic data and kinetics.

"An exothermic reaction occurs 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."

It seems from the above 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. The quotations show that a significant proportion of the undergraduates are still unaware of the fact that it is not correct to make estimation about the kinetics of a chemical reaction by using thermodynamic quantities. Some of these misunderstandings may be due to an inability to differentiate the kinetic and thermodynamic data. 12% of the responses asserted that endothermic reactions occur fast. The responses centred on the idea that the rate of exothermic reactions is conversely affected by the temperature increase but increase of 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 occur 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."

The quotation shows that the respondent confused the ambient temperature and the optimum temperature at which a reaction occurs with a maximum yield. However, both the rate and the yield are determined by one temperature: the ambient temperature and this ambient temperature is what the respondent is talking about. The respondent seems to confuse reaction rate and yield. For an exothermic reaction the student expects the reaction to go faster at lower temperature while in fact the yield is better, not the rate.

Conclusions and Implications for Teaching

The findings of this study revealed that the prospective chemistry teachers attempted to interpret the kinetics of several phenomena by using thermodynamics data leading students to develop misconceptions. They considered that there is a direct relationship between: *solubility* and *dissolution rate*; *equilibrium constant* and *reaction rate*; *equilibrium* and *reaction rate, Gibbs free energy* and *reaction rate,* and *enthalpy change* and *reaction rate*.

The above conceptions of the prospective teachers suggest that they did not adequately understand the difference between kinetics and thermodynamics and confused these two domains which are, in fact, two totally different aspects of phenomena. Solubility, the equilibrium constant and free energy change are all thermodynamic quantities. Solubility corresponds to the maximum amount of a solute dissolved in a solvent/solution at a given temperature; the equilibrium constant indicates the extent of a reaction, and Gibbs free energy gives a direct criterion for the spontaneity of a reaction. In a broader sense, the study of thermodynamics is an important subject in chemistry that should help students to understand energy transfer, the direction in which chemical processes go and why they happen. However, thermodynamics provides no information about the kinetics of a reaction. The rate of reaction is the subject of kinetics; while above quantities are subject of thermodynamics.

It is apparent from the interviews that the prospective teachers had difficulty in differentiating kinetics from thermodynamics, as they attempted to use thermodynamic data to explain the kinetics of a reaction. This perhaps may lead future students of those prospective teachers holding similar misconceptions.

It is difficult to discover the sources of the students' misconceptions. However, it has been suggested that the following possibly could negatively influence students' conceptions. Previous research studies (Carson & Watson, 1999; 2002; Sozbilir, 2001; 2002; Sozbilir & Bennett, 2006; 2007) indicated that many students showed a superficial understanding of thermodynamics and had difficulties with the nature of fundamental

thermodynamic quantities such as internal energy, enthalpy, free energy, equilibrium. The misconceptions about these essential concepts of thermodynamics could play a key role in causing the students to develop new misconceptions relating the relationship between kinetics and thermodynamics.

In addition to this, it is our anecdotal evidence that most of the time assigned for teaching thermodynamics is dedicated to derivation of mathematical equations and teaching of algorithmic problem solving rather than to the development of conceptual understanding. This makes students' understanding of basic ideas limited, distorted or wrong. Consequently, students in general retain their everyday conceptions and do not gain faith in the value of learning the meaning of science concepts (Carson & Watson, 1999; 2002).

Another possible cause for misconceptions could be that the students' understanding of basic science concepts is sometimes overestimated and their difficulties in achieving understanding of basic scientific concepts are underestimated by science lecturers. If lecturers become aware of the sources of students' misunderstanding and their limited value of study of scientific concepts, these will make teaching of science concepts much more feasible (Sozbilir, 2004).

Lastly, this paper indicates that students had conceptual difficulties on the nature of chemical thermodynamics and kinetics. We suggest that the conceptual difficulties diagnosed in this study may be widespread among undergraduates elsewhere and should not be treated as specific only to the present subjects of the study. We hope that the findings reported here may contribute to understanding of undergraduates' difficulties and can be utilized in research that develops teaching strategies to overcome such difficulties.

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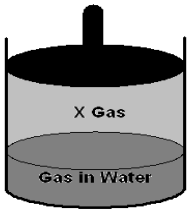
Appendix 1. Diagnostic questions used in the test.

1. At constant temperature X gas is in equilibrium with its aqueous solution as seen in the container shown left. At constant pressure, how the *solubility* and *dissolving rate* of X gas in water would be affected from temperature increase?



Please explain your answer as carefully as you can.

2. The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1 $A + B \leftrightarrows C$ $K_1 = 10^{-5}$

Reaction 2 $X + Y \leftrightarrows Z$ $K_2 = 10^{-10}$

On the basis of this information, can you compare the rate of these two reactions? If so, how would the rate of two hypothetical reactions given above compare?

Please explain your answer as carefully as you can.

3. $SO_{2(g)} + ½\ O_{2(g)} \leftrightarrows SO_{3\,(g)} + \text{Heat}$

According to the above exothermic reaction, at constant pressure how would the amount and the formation rate of SO_3 (rate of forward reaction) changes with temperature increase?

Please explain your answer as carefully as you can.

4. The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1

$A + B \leftrightarrows C + D$ $\Delta G_1 = -10$ kJ mol^{-1}

Reaction 2

$X + Y \leftrightarrows Z + W$ $\Delta G_2 = -100$ kJ mol^{-1}

On the basis of this information, can you compare the rate of these two reactions? If so, how would the rate of two hypothetical reactions given above compare?

Please explain your answer as carefully as you can.

5. The chemical equations given below represent two hypothetical reactions. The two reactions occur at the same temperature.

Reaction 1

$A + B \leftrightarrows C + D$ $\Delta H_1 = -50$ kJ (Exothermic)

Reaction 2

$E + F \leftrightarrows G + H$ $\Delta H_2 = 50$ kJ (Endothermic)

On the basis of this information, can you compare the rate of these two reactions? If so, how would the rate of two hypothetical reactions given above compare?

Please explain your answer as carefully as you can.