Prospective chemistry teachers' misconceptions about colligative properties: boiling point elevation and freezing point depression

Tacettin Pinarbasi*, Mustafa Sozbilir and Nurtac Canpolat

Received 20th February 2008, Accepted 13th July 2009
DOI: 10.1039/b920832c

This study aimed at identifying prospective chemistry teachers' misconceptions of colligative properties. In order to fulfill this aim, a diagnostic test composed of four open-ended questions was used. The test was administered to seventy-eight prospective chemistry teachers just before qualifying to teaching in secondary schools. Nine different misconceptions were identified and qualitatively discussed. The results have implications for teaching colligative properties and in general tertiary level teaching, suggesting that a substantial review of teaching strategies is needed.

Keywords: chemistry teacher training, misconception, colligative properties, solutions, physical properties

Introduction

In the past three decades, aiming to enhance meaningful conceptual learning in science many researchers have sought to discover what ideas children hold about scientific concepts and how these understandings impinge on their learning in science (Duit, 2006). Research-based evidence in this area indicates that a majority of students lack scientific understanding of even basic science concepts (Weiss, 1994). The reason for this is that, from an early age, pupils hold and develop their own ideas of the natural world before any formal teaching or learning in the classroom begins (Driver *et al*., 1994). When learning science at school they sometimes make inappropriate links to their prior knowledge, and hence the meanings they construct are not those intended by the teacher (Osborne and Wittrock, 1983). These inconsistencies between the students' views and the scientifically accepted views are called misconceptions, alternative conceptions, naïve conceptions (Driver *et al.,* 1994). In general, these misconceptions may be highly resistant to change, and remain intact for many years essentially unaffected by classroom teaching. It is well known that the ideas pupils possess prior to classroom teaching are crucial: *"the most important single factor influencing learning is what the learner already knows"* (Ausubel, 1968, p.7).

The constructivist theory of learning suggests that knowledge is constructed through a process of interaction between an outside stimulus and conceptions that already exist in the learner's head. During this process, some of the existing conceptions are modified and some new ones created. 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). This notion was articulated by McCloskey (1983), and supported by Engel *et al.* (1986). McCloskey argued that people develop well-articulated naive theories based on their everyday experiences. Furthermore, he argued that these naive theories are consistent across individuals. On the other hand, diSessa (1988) raised issues about the nature of misconceptions. diSessa questioned the views of McCloskey and argued that people hold loosely connected, fragmented ideas, some of which reinforce each other but none of which have the rigor of theory. In diSessa's words, students have 'knowledge in pieces'. diSessa went on to suggest that there is evidence in his work of students making up explanations spontaneously at the point when they are faced with a question, drawing where they can on core intuitions based on everyday experience. These notions were called phenomenological primitives, or p-prims. Later work (Southerland *et al*., 2001) provided additional support for the notion that students make up explanations spontaneously. However, in this study, the term 'misconceptions' was used to describe students' responses that were scientifically incorrect or unacceptable

During the past three decades, although there has been considerable research into students' understanding in chemistry, there has been relatively limited research focusing on undergraduates' understanding advanced chemistry concepts. Although there were studies carried out previously on primary and secondary students' understandings of chemistry, and teaching basic chemical concepts effectively (*e.g*. Tytler, 2000, Zikovelis and Tsaparlis, 2006), in recent years research has started to concentrate on undergraduates' and prospective teachers' understanding of advanced concepts in chemistry, such as chemical equilibrium (Banerjee, 1991; Thomas, 1997; Van Driel, 2002), chemical kinetics (Cakmakci *et al.,* 2006), phase changes (Azizoglu *et al.,* 2006), vaporization, vapor pressure and vaporization rate (Canpolat, 2006; Canpolat *et al*, 2006), enthalpy (Beall, 1994; Carson and Watson, 1999; Sozbilir and Bennett, 2006), entropy (Selepe and Bradley, 1997; Carson and Watson, 2002;

Atatürk University, KK Education Faculty, Department of Secondary Science and Mathematics Education, 25240-Erzurum, Turkey. E-mail: tacettin_p@yahoo.com

Sozbilir and Bennett, 2007)), Gibbs free energy (Granville, 1985; Banerjee, 1995; Sozbilir, 2002) and also how to teach the concepts of chemistry effectively (Tsaparlis, 2005; Van Driel and Graber, 2002). Overwhelmingly, evidence suggests that undergraduates' understanding of advanced ideas in chemistry is very poor. Part of the difficulty rests with the nature of chemistry itself (*i.e.*, the abstract and complex nature of chemical change), but more seems to stem from the ways in which the concepts are customarily taught without regard to what is known about students' learning and about the content structure of the domain (Cakmakci *et al.,* 2006).

There are several concepts in chemistry at basic and advanced levels that are difficult to understand, because their operational definitions involve sophisticated reasoning. The concepts of colligative properties are among those. Tytler (2000) studied first-year and sixth-year students' conceptions of evaporation and condensation through challenging activities based on these concepts. The results suggest that while there was substantial overlap between the conceptions used by the first-year and sixth-year students, there were also substantial differences in the patterns of conceptions, the epistemological sophistication demonstrated, and the structure of their explanations. The older children had much greater access to the phenomenological language commonly used in relation to evaporation and condensation (moisture, vapor, humidity, evaporation). Sixth-year students showed sufficient familiarity with a range of evaporation and condensation phenomena to indicate the prior formulation of questions concerning the nature of the changes to water. This does not mean that the older children do not have ontological confusions similar to the younger children regarding the distinction between substance and properties such as temperature and smell, or between dampness, moisture, and water. However, the older children were in a better position to reflect productively on these matters, and in particular, could be expected to respond to teaching about evaporation and condensation by accurately incorporating the new knowledge with previous experience and understandings.

More recently, Canpolat (2006) and Canpolat *et al.* (2006) studied prospective chemistry teachers misconceptions on evaporation, evaporation rate and vapor pressure. The common misconceptions identified in the Canpolat *et al*. (2006) study were grouped under six headings: inadequacies in understanding liquid–water equilibrium at conceptual level, 'vaporization occurs simultaneously with boiling', 'a liquid has to be heated in order to vaporize', 'the pressure of vapor in equilibrium with its liquid is affected by volume changes, as in the case of ideal gases', 'vapor pressure depends on the amount and volume of matter' and 'misinterpretation of the relationship between the vapor pressure and the boiling point of a liquid' and were discussed in detail. On the other hand, the Canpolat (2006) study focused particularly on students' misconceptions related to evaporation, evaporation rate, and vapour pressure, and identified eight different misconceptions (see pp. 1762-1767 for an in depth discussion). However, none of these studies were focussed on prospective chemistry teachers' understanding of the concepts of colligative properties, which is necessary in order to understand the nature of several phenomena, such as vaporization, melting, freezing and sublimation. Moreover, our literature review suggests that there is no research focused on students' conceptions of colligative properties at the undergraduate level, although a few studies discussed colligative properties qualitatively, (Rioux, 1973; Mundel and Dreisbach, 1990; De Muro *et al*., 1999; McCarthy and Gordon-Wyle, 2005) and looked at their application into practice (Plumb, 1976; Sund, 1989). Therefore, this study aimed to explore the misconceptions concerning colligative properties among Turkish prospective chemistry teachers. Being aware of prospective chemistry teachers' misconceptions concerning colligative properties allows us to predict some of the difficulties that teachers and their students may encounter when studying this topic. The research question answered in this study is:

> What misconceptions – if any – about boiling point elevation and freezing point depression are found among Turkish prospective chemistry teachers?

Method

Sampling

The present study employed a quantitative approach in order to achieve the aim described above, and the results are presented descriptively. Data were collected from seventy-eight prospective chemistry teachers. Forty-two of them were enrolled to *Master Without Thesis Combined With Bachelors Degree* and thirty-six to the *Master Without Thesis* at Kazım Karabekir Education Faculty of Atatürk University in Turkey during the 2004-2005 academic year. Participation in the study was voluntary. The Department of Chemistry Teacher Training runs two different programs. The *Master Without Thesis* (similar to the PGCE in the UK) which is one year long (two semesters), a *postgraduate* teacher training course, qualifying chemistry graduates for teaching secondary school pupils aged 14-17, together with regular chemistry teacher training which is a five year program entitled *Master without Thesis Combined with Bachelor's Degree*, qualifying chemistry teachers for teaching also at the same level. Graduates who have BSc in chemistry could enroll on the *Master Without Thesis* program if they want to be chemistry teachers in secondary schools. The *Master without Thesis Combined with Bachelors Degree* course accepts students through a centralized nationwide examination, which is held every year and is administered by the *Student Selection and Placement Center* (ÖSYM). Students in these two programs took the same chemistry courses with the same content (*e.g.*, general chemistry, physical chemistry). Colligative properties are taught in both general chemistry in the first year and physical chemistry in the third year. The content of the colligative properties are the topics covered in any conventional general chemisty and physical chemistry textbook (*e.g.* Atkins and Jones, 1997; Atkins and Paula, 2002; Petrucci *et al.*, 2002).

 This journal is © The Royal Society of Chemistry 2009

Table 1 Prospective chemistry teachers' misconceptions as identified by the diagnostic test (N=78)

	Frequency	%
Boiling point elevation / freezing point depression		
1. Boiling point elevation / freezing point depression occurs due to interactions between the water and salt particles	41	52
2. Boiling point elevation / freezing point depression occurs: • because the boiling point of salt is higher than the boiling point of water • because the freezing point of salt is lower than the freezing point of water.	17	22
3. Boiling/freezing temperatures of liquids with higher density would be higher/lower than the liquids with lower density.	13	17
4. Alcohol does not change or increases the freezing point of water.	51	65
Boiling temperature change		
5. Boiling temperature does not stay constant as some of the heat will be spent on the salt	37	47
6. Boiling temperature is not constant as water boils first then salt boils.	18	23
7. Boiling temperature does not stay constant as density of water increases after boiling starts	16	21
Freezing temperature change		
8. Freezing temperature is not constant as water freezes first then salt freezes	19	24
9. Freezing temperature does not stay constant as the density of water increases during freezing	18	23

Data collection tools

Data were collected through a diagnostic test comprising four open-ended questions specifically developed for this study (see the Appendix). All questions were piloted, and the required modifications were made prior to the administration of the test. The content validity of the test questions was assessed by four chemistry lecturers. The test was conducted under normal class conditions without previous warning two month prior to graduation. Respondents were allowed a normal class period, which is 50 minutes. Students were informed that the results of the test would be used for research purposes only and would be kept confidential.

Data analysis

The written responses were read by the authors individually and the misconceptions were determined. Once the misconceptions were identified, then all responses were read through again, and the frequencies were determined and the percentages were calculated. The results are presented decriptively and discussed. Sample quotes from the written responses are provided. Because the study was conducted in Turkish, the quotations were translated into English by the authors.

Results

The results are summarised in Table 1, and each misconception identified is discussed. The misconceptions are grouped under three headings in order to make discussion clearer. The frequencies given in the Table indicate the number of prospective chemistry teachers who showed the particular misconceptions.

Boiling point elevation/freezing point depression

The responses given to the first question revealed three misconceptions. The most common (52%) misconception was that boiling point elevation and freezing point depression occurs because of the interactions between the water and salt particles. This could be seen in the following quotations:

> *The evaporation of water would be difficult due to the interactions between salt ions and water molecules, therefore, boiling temperature increases.*
>
> *Salt [ions] attracts more strongly water molecules preventing water molecules from gathering, thus freezing of water.*
>
> *According to $NaCl + H_2O \rightarrow NaOH + HCl$ equation, bonds occurring between OH^- and Na^+ / H^+ and Cl^- ions in water cause freezing point depression and boiling point elevation. Salt ions prevent water molecules from being in an order by entering between them. As a result of this, freezing temperature decreases. In the case of boiling, as some of the heat given is spent for removing water molecules which hydrate salt ions, boiling temperature increases.*

The written responses quoted above suggest that prospective teachers thought that salt added to water will be ionized and there will be interactions between these ions and water molecules and it is these interactions that cause freezing point depression and boiling point elevation. This result is in good agreement with previous research result (Pinarbasi *et al*. 2006). Some of the prospective teachers (22%) explained the freezing point depression or boiling point elevation in terms of the boiling or freezing temperature of the salt. Those who held this view, argued that the solution boils at a temperature between the salt's and the water's boiling temperature, and this temperature would be above the water's boiling temperature, as salt has a higher boiling point than water. Similarly, prospective teachers thought that freezing point of the solution will be somewhere between salt's and water's freezing point, and it would be lower than water's freezing point as salt has lower freezing point than water. Some excerpts representing this view are given below:

> *The freezing point of a solution depends on the freezing points of solute and solvent. Solution freezes somewhere between these two freezing temperatures. Boiling point [of a solution] would be somewhere between the boiling points [of solute and solvent]*
>
> *As the freezing point of salt is lower than freezing point of water, the solution's freezing point would be somewhere between these two values. Similarly, the [salt/water] mixture boils at a temperature over than waters' boiling point as salt has higher boiling temperature than water.*

The above responses indicate that prospective teachers thought that the freezing point of salt would be lower than

water's freezing point, failing to note that salt is already a solid. This view could be considered as an extension of the view that the boiling point of salt would be higher than that of water's boiling point.

Another misconception identified in 17% of the written responses given to the first question was that the boiling temperature of a liquid with higher density would be higher and the freezing temperature lower than those of a liquid with lower density, as seen in the following quotes:

The density of water increases when salt is added to water. Thus, water boils at higher temperature and freezes at lower temperature. Because, boiling temperature of liquids with higher densities would be higher, whereas freezing temperature of liquids with higher densities would be lower.

The freezing point decreases and boiling point increases due to an increase in the density of water. The higher density means the more difficult to freeze and to boil.

The majority of the prospective teachers who held the above views asserted that the changes occurring in boiling and freezing temperatures are due to impurities, which cause an increase in the density of water. It appears that prospective teachers are confusing the density of pure water with that of salt/water solutions. Salt/water solution has been considered as a high density liquid (relative to water) rather than as a mixture, and therefore they thought that the higher density of the liquid means the higher boiling /lower freezing point.

The responses given to the second question, which asks the participants to compare the freezing points of alcohol/water mixture and pure water, showed that prospective chemistry teachers have a misconception, according to which either alcohol has no effect or increases the freezing point of water. About one in three (35%) of them thought that the addition of alcohol increases the freezing point of water, while another 30% of them argued that alcohol addition does not affect the freezing point. The following excerpts taken from the written responses exemplify the case:

Alcohol is volatile; it increases the freezing point of water when added to water.

While salt decreases the freezing point, alcohol increases the freezing point as it is a liquid and also volatile.

While an involatile matter decreases the freezing point, a volatile matter increases the freezing point of water. Therefore, alcohol/water mixture has higher freezing point than pure water.

The above responses clearly indicate that prospective teachers thought that only involatile solid solutes decrease the freezing point; in the case of volatile solutes the freezing point increases. The reason behind this misconception is perhaps due to the emphasis given to the involatile solutes in the definition of colligative properties in textbooks (see Atkins 1996, p. 136; Atkins and de Paula 2002, p. 175) and the examples used by teachers. This emphasis given to the involatile solutes in the definition of colligative properties perhaps led students to think that freezing point depression occurs only in the case of involatile solutes. This view can clearly be seen from one of the written responses given below:

The colligative properties are related to involatile solutes in the physical chemistry textbook. Therefore, in my view, alcohol would increase the freezing point of water.

On the other hand, some of the prospective teachers argued that alcohol does not affect the freezing point of water, as stated above. Their reasoning for this was the volatility of alcohol:

In my view it does not affect as alcohol is a volatile.

As involatile solutes decrease the freezing point, volatile alcohol either does not change or increases.

Some of the prospective teachers who have this view argued that alcohol does not affect the freezing point of water as it is not ionized in water. This view could be seen in the following quote taken from a written response:

… alcohol does not change the freezing point of water as it does not ionize like salt ionizes in the water.

Boiling temperature change

The analysis of written responses given to the third question which questions the reason of temperature change of salt water during boiling is given in Table 1. As seen from the table, prospective teachers have three different misconceptions about this case. The most common one (47%) is the view that boiling temperature does not stay constant, as some of the heat will be used for the salt. The following written responses reflect this view:

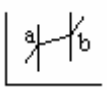
The temperature will gradually increase in the presence of salt, since some of the heat given will be used on salt.

Salt ions would cause to increase the temperature by taking some of the heat given.

The boiling temperature of pure water does not change. The heat given is used only for the evaporation of water. I think, in the case of salt solution, the heat given is not used only to evaporate the water, instead some of it is taken by the salt. Therefore, the temperature increases.

As seen from the above excerpts, prospective teachers correctly explained why the temperature of pure water stays constant during boiling. They also tried to explain the temperature change of salt water in a similar way by comparing it with pure water (see especially the third quotation given above). Students who held this view thought that the heat provided to the system during boiling is not solely used for the evaporation of the water, instead some of the heat is absorbed by the salt in the solution, and as a result of this the total energy absorbed by the system increases, thus the temperature increases.

Another explanation, given by 23% of the respondents about why boiling temperature of salt solution does not stay constant, is that water in the solution boils first, then the salt boils, therefore the boiling temperature does not stay constant. The prospective teachers here thought that the components in the solution boil at their boiling temperatures independently from each other, and as a result of this the boiling temperature changes. They state that water boils first then salt follows it. The responses quoted below represent this view:



Solutions are impure. Firstly water boils, then salt boils with increasing temperature and therefore the boiling temperature does not stay constant. As seen from the graph, water starts to

 This journal is © The Royal Society of Chemistry 2009

boil at point 'a' and the salt starts boiling at point 'b'.

As water boils first then salt follows it, the temperature does not stay constant.

A previous report (Blanco and Prieto, 1997) suggests that students have a similar misconception in that during the boiling of a solution that contains an involatile solute, a certain amount of the solute evaporates and escapes the solution together with the solvent.

Another misconception identified through the analysis of the responses given to the third question, which appeared in almost one in five (21%) of the prospective teachers' responses, was that the temperature of the solution does not stay constant during boiling because of the increase in density. This has some similarity with the third misconception identified through the responses given to the first question, that boiling temperatures of liquids with higher density would be higher than the liquids with lower density. It appears that prospective teachers consistently displayed the view that the higher the density of a liquid, the higher boiling point of a liquid. This view could be seen in the following responses:

As water evaporates its density increases, thus the boiling temperature increases as the boiling temperature of liquids with higher density is higher.

Density of water increases during boiling and therefore the boiling temperature increases during boiling.

Freezing temperature change

The misconceptions identified from the responses given to the fourth question have similarities with the last two misconceptions identified and discussed in connection with the third question. Prospective teachers argued that the temperature change during freezing is due to the different freezing points of the components of the solution. A similar approach was also identified in the responses given to the first question, where 24% of the respondents thought that first water freezes then salt freezes. The following responses represent this view:

The temperature changes as water freezes first, then salt freezes.

The temperature changes are due to impurities. Water freezes first, then the impurities freeze. Therefore, the temperature does not stay constant.

Another misconception revealed by the students' responses was identified, when 23% of them also argued that the temperature during freezing does not stay constant, as the density of water increases during freezing:

The density of water increases as water freezes, and therefore freezing temperature does not stay constant.

The temperature does not stay constant as the density of water increases. Higher the density of water, lower the freezing temperature.

Similarly to the discussions above, prospective teachers postulated a direct relationship between the density of matter and freezing temperature. According to this view, liquids with higher densities have higher boiling and lower freezing temperatures.

Conclusions and implications

The findings of this study, which examines prospective chemistry teachers' understandings of boiling point elevation and freezing point depression of solutions, suggest that prospective teachers have significant misconceptions about the nature of colligative properties. The misconceptions identified fall into three groups:

- The reasons for boiling point elevation and freezing point depression,
- The effect of a volatile solute on the freezing point of a solution,
- The reasons for temperature changes of a solution during boiling and freezing.

Regarding boiling point elevation and freezing point depression, the prospective teachers stated that it occurs because of: (i) the attractive forces between salt ions and water molecules, (ii) an increase in the density of water caused by salt addition, (iii) the higher boiling and the lower freezing points of salt than those of water. These findings suggest that prospective teachers have a naive understanding of colligative properties and an uncertain grasp of some empirical facts: *e.g*. the higher freezing point of salt than that of water. The misconception that inter-molecular attractions cause the boiling point elevation and freezing point depression is among the most common one, as previously shown by Pinarbasi *et al*. (2006).

On the other hand, a significant number of participants thought that a solute has to be involatile in order for freezing point depression to take place. As a result of this view, some of the participants thought that freezing point either does not change or increases in the case of a volatile solute. In fact, the volatility or involatility of a solute is not a determining factor for freezing point depression of a solution. Freezing point depression is independent of the volatility of the solute, although this is not the case for boiling point elevation. Whatever a solute, even a gas, it depresses the freezing point of its solution. This misconception has, perhaps, originated from textbooks, as the importance of a solute being involatile for boiling point elevation is stressed, but it is not stressed that freezing point depression is independent of the volatility of a solute (see Atkins 1996, p.136.; Bell 2005, p.558). In addition, textbooks generally provide examples of involatile solutes (such as ionic and covalent molecular solids) in exercises and problems to explain freezing point depression (*e.g.* Atkins 1996, pp. 136-137; Hill and Petrucci 1999, pp. 535-537; Petrucci and Harwood 1997, pp.488-490). In order to prevent this common misconception, it is suggested that textbook writers should pay more attention to stressing that the involatility of solutes is a necessity for boiling point elevation but it is *not* necessary for freezing point depression, as it is in Levine (1988, p. 317), and examples from both volatile and involatile solutes should be chosen in exercises and problems to explain freezing point depression, as it is in Bell (2005, p. 563). It is also suggested that textbooks should provide exercises and molecular interpretations together (*e.g.* Atkins 1997, pp. 222-226) in order to help both teachers and students understand the phenomena of colligative properties.

From the written responses given about the reasons for the change in the temperature of a solution during boiling or freezing, it was also found that prospective teachers are not able to produce explanations at the molecular level. Instead, the majority of them superficially thought that the heat given to the solution is absorbed by the salt; first water then salt boils, and the density of water increases during boiling. It is difficult to locate the sources of these misconceptions. However, it could be suggested that teachers may qualitatively discuss the phenomena first, and this should be followed by solving algorithmic problems. With this perspective, in order for conceptual understanding to take place, lessons may start from where colligative properties have arisen, and a discussion may be given at the molecular level. Just defining what the colligative properties are, and giving the names of these properties may not be enough for students to comprehend these concepts.

In addition, the limitations of the definitions given about colligative properties should be clearly discussed and the conditions for the validity of these definitions should be considered. Otherwise, as seen from the findings of this study, students may possibly develop misconceptions by overgeneralizing that involatility of a solute is necessary for all cases of colligative properties. For instance, the misconception shared by a significant number of participants of this study that alcohol does not change or increase the freezing point of aqueous alcohol solution could be considered as a result of such an overgeneralization.

The results of this study indicate that prospective teachers are having significant learning deficiencies at the conceptual level. In order for prospective teachers to have a consistent and correct conceptual understanding, they have to be able to develop meaningful understanding of these concepts. It is believed that the findings of this study may provide some insights for meaningful learning of colligative properties both for students and teachers.

Acknowledgements

We would like to thank the reviewers for their valuable suggestions which significantly helped to improve the manuscript.

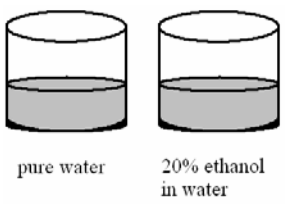
Appendix

Diagnostic questions used in the test

1. It is known that at atmospheric pressure, a dilute aqueous solution of NaCl has higher boiling point and lower freezing point than pure water. How could you explain this?
Please explain your answer as fully as you can.

The expected answer: It should be stated that there is no single answer that could be accepted as correct. However, different views can be elaborated. In thermodynamic terms, the boiling point increase can be explained in terms of the *vapor pressure* or of the *chemical potential* of the solvent. In terms of vapor pressure, a liquid boils at the temperature when its vapor pressure equals the surrounding pressure. For the solvent, the presence of the solute decreases its vapor pressure. An involatile solute (in this case NaCl) has a vapor pressure of zero, and the vapor pressure of the solution is the product of the vapor presure of the pure solvent (water) and the mole faction of the solvent in the solution (*i.e*. Raoult's law; Hill and Petrucci 1999, p. 530). As the mole fraction of the solvent (water) decreases in the solution, vapor pressure of the solution decreases. Thus, a higher temperature is needed for the vapor pressure to reach the surrounding pressure, and the boiling point increases. In terms of chemical potential,, at the boiling point, the liquid phase and the gas (or vapor) phase have the same chemical potential (or vapor pressure), meaning that they are energetically equivalent. The chemical potential is dependent on the temperature, and at other temperatures either the liquid or the gas phase has a lower chemical potential and is more energetically favourable than the other phase. This means that when a involatile solute is added, the chemical potential of the solvent in the liquid phase is decreased by dilution, but the chemical potential of the vapour above the solution is not affected. This means in turn that the equilibrium between the liquid and gas phase is established at another temperature for a solution than a pure liquid, i.e., the boiling point increases. The cause of the phenomenon of freezing-point decrease is analogous to the boiling point elevation. However, the magnitude of the freezing point depression is larger than the boiling point elevation for the same solvent and the same concentration of a solute. Because of these two phenomena, the liquid range of a solvent increases in the presence of a solute (Atkins 1996, p. 136).

2. There are two beakers containing pure water and an aqueous ethanol solution (20% ethanol at constant pressure (shown left). What would you expect the relative freezing temperatures of pure water and aqueous ethanol solution to be? Please explain your answer as fully as you can.



The expected answer: The freezing point of the ethanol/water mixture is lower than that of pure water, and also, the freezing point depression of all solutions is independent of the volatility of solute.

3. It is known that the boiling temperature of a dilute salt solution in an open container does not stay constant during boiling. How would you account for this?
Please explain your answer as fully as you can.

The expected answer: Colligative properties are dependent on the concentration of the solute present. The greater amount of solute is dissolved in a solvent, the greater the change in the colligative properties. The boiling temperature of a solution is dependent on the concentration of a solution. As the solution boils, some of the water evaporates, hence the concentration of the solution increases and this increases the boiling temperature of the solution until the solution reaches saturation.

 This journal is © The Royal Society of Chemistry 2009

4. It is known that freezing temperature of a dilute salt solution does not stay constant during freezing. How would you account for this?
Please explain your answer as fully as you can.

The expected answer: Similarly to the above response, colligative properties are dependent on the concentration of the solute. The greater amount of solute is dissolved in a solvent, the greater the change in the colligative properties. The freezing temperature of a solution is dependent on the concentration of a solution. As the water freezes, the concentration of the remanining solution increases and this causes the freezing temperature of the solution to decrease until the solution reaches saturation.

References

Atkins P., (1996), *The elements of physical chemistry*, 2nd ed., Oxford University Press: Oxford.

Atkins P., (1997), *Physical chemistry*, 5th ed.; Oxford University Press: Oxford.

Atkins P. and de Paula J., (2002), *Atkins' Physical Chemistry*, 7th ed., Oxford University Press: Oxford.

Atkins P. and Jones L., (1997), *Chemistry: molecules, matter, and changes,* 3rd ed., Oxford University Press: Oxford.

Ausubel D. P., (1968), *Educational psychology, a cognitive view*, Holt, Rinehart and Winston, NC Press, London, UK.

Azizoğlu N., Alkan M. and Geban Ö., (2006), Undergraduate pre-service teachers' understandings and misconceptions of phase equilibrium, *J. Chem. Educ.*, **83**, 947-953.

Banerjee A. C., (1991), Misconceptions of students and teachers in chemical equilibrium, *Int. J. Sci. Educ.*, **13**, 487–494.

Banerjee A. C., (1995), Teaching chemical equilibrium and thermodynamics in undergraduate general chemistry classes, *J. Chem. Educ.*, **72**, 879-881.

Beal H., (1994), Probing student misconception in thermodynamics with in-class writing, *J. Chem. Educ.*, **71**, 1056-1057.

Bell J. A., (2005), *Chemistry: a project of the American Chemical Society*, W.H. Freeman and Company: New York.

Blanco A. and Prieto T., (1997), Pupils' views on how stirring and temperature affect the dissolution of a solid in a liquid: a cross-age study (12 to 18), *Int. J. Sci. Educ.*, **19**, 303-315.

Cakmakci G., Leach J. and Donnelly J., (2006), Students' ideas about reaction rate and its relationship with concentration or pressure, *Int. J. Sci. Educ.*, **28**, 1795-1815.

Canpolat N., (2006), Turkish undergraduates' misconceptions of evaporation, evaporation rate, and vapour pressure, *Int. J. Sci. Educ.*, **28**, 1757-1770.

Canpolat N., Pinarbasi T. and Sozbilir M., (2006), Prospective teachers' misconceptions of vaporization and vapor pressure, *J. Chem. Educ.*, **83**, 1237-1242.

Carson E. M. and Watson J. R., (1999), Undergraduate students' understanding of enthalpy change, *Univ. Chem. Educ.*, **3**, 46-51.

Carson E. M. and Watson J. R., (2002), Undergraduate students' understanding of entropy and Gibbs free energy, *Univ. Chem. Educ.*, **6**, 4-12.

De Muro J. C., Margarian H., Mkhikian A., Hwi No K. and Peterson A. R., (1999), An inexpensive microscale method for measuring vapor pressure, associated thermodynamic variables, and molecular weight, *J. Chem. Educ.*, **76**, 1113-1116.

diSessa A. A., (1988), Knowledge in pieces, in Forman G. and Pufall P (eds.), *Constructivism in the computer age*, Hillsdale, NJ: Erlbaum, pp. 49-70.

Driver R., (1989), Students' conception and the learning of science, *Int. J. Sci. Educ.*, **11,** 481-490.

Driver R., Squires A., Rushworth P. and Wood-Robinson V., (1994), *Making sense of secondary science: research into children's ideas*; Routledge: London.

Duit R., (2006), Bibliography – STCSE (Students' and teachers' conceptions and science education), *http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html*

Engel Clough E. and Driver R., (1986), A study of consistency in the use of students' conceptual frameworks across different task contexts, *Sci. Educ.*, **70**, 473-496.

Granville, M.F. (1985). Student misconceptions in thermodynamics, *J Chem Educ*, 62(10), 847-848.

Hill J. W. and Petrucci R. H., (1999), *General chemistry: an integrated approach*, 2nd ed., Prentice-Hall International: London.

Levine I. N., (1988), *Physical chemistry,* 3rd ed., McGraw-Hill: New York.

McCarthy S. M. and Gordon-Wylie S. W., (2005), A greener approach for measuring colligative properties, *J. Chem. Educ.*, **82**, 116-119.

McCloskey M., (1983), Naive theories of motion, in Gentner D. and Stevens A.(eds.), *Mental models*, Hillsdale, NJ: Lawrence Erlbaum Associates, pp. 299-324.

Mundel D. W. and Dreisbach J. H., (1990), Heat of solution and colligative properties: an illustration of enthalpy and entropy, *J. Chem. Educ.*, **67**, 426-427.

Osborne R. J. and Wittrock M. C., (1983), Learning science: a generative process, *Sci. Educ.*, **67**, 489-508.

Petrucci R. H.and Harwood W. S., (1997), *General chemistry: principles and modern applications*, 7th ed., Prentice Hall International: London.

Petrucci R. H., Harwood W. S. and Herring F. G., (2002), *General chemistry: principles and modern applications*, 8th ed., Prentice Hall International: London.

Pınarbaşı T., Canpolat N., Bayrakçeken S. and Geban Ö., (2006), An investigation of effectiveness of conceptual change text-oriented instruction on students' understanding of solution concepts, *Res. Sci. Educ.*, **36**, 313-335.

Plumb R. C., (1976), Sparkling pure water in a swimming pool, *J. Chem. Educ.*, **53**, 49-50.

Rioux F., (1973), Colligative properties, *J. Chem. Educ.*, **50**, 490-492.

Selepe C. and Bradley J., (1997), Student teacher's conceptual difficulties in chemical thermodynamics, in Sanders M.(ed.), *SAARMSE Fifth Annual Meeting*, University of the Witwatersrand, Johannesburg, South Africa, pp. 316-321.

Southerland S. A., Abrams E., Cummins C. L. and Anzelmo J., (2001), Understanding students' explanations of biological phenomena: conceptual frameworks or p-prims? *Sci. Educ.*, **85**, 328-348.

Sozbilir M., (2002), Turkish chemistry undergraduate students' misunderstandings of Gibbs free energy, *Univ. Chem. Educ.*, **6**, 73-83.

Sozbilir M.and Bennett J. M., (2006), Turkish prospective chemistry teachers' misunderstandings of enthalpy and spontaneity, *Chem. Educator*, **11**, 355-363.

Sozbilir M.and Bennett J. M., (2007), A study of Turkish chemistry undergraduates' understanding of entropy, *J. Chem. Educ.*, **84**, 1204-1208.

Sund R., (1989), Quantifying a colligative property associated with making ice cream, *J. Chem. Educ.*, **66**, 669.

Thomas P. L., (1997), *Student conceptions of equilibrium and fundamental thermodynamic concepts in college physical chemistry*, Unpublished Ph.D. thesis, University of Northern Colorado, Greeley, Colorado, USA.

Tsaparlis G., (2005), Non-algorithmic quantitative problem solving in university physical chemistry: a correlation study of the role of selective cognitive factors, *Res. Sci. Tech. Educ.*, **23**, 125-148.

Tytler R., (2000), A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: dimensions of conceptual progression, *Int. J. Sci. Educ.*, **22**, 447–467.

Van Driel J. H., (2002), Students' corpuscular conceptions in the context of chemical equilibrium and chemical kinetics, *Chem. Educ. Res. Pract.*, **3**, 201–213.

Van Driel J. H. and Gräber , W., (2002), The teaching and learning of chemical equilibrium, in Gilbert J. K., De Jong O., Justi R., Treagust D. F. and Van Driel J. (eds.), *Chemical education: towards research-based practice*, Kluwer Dordrecht, the Netherlands, pp. 271-292.

Weiss I., (1994), *National survey of science and mathematics education*;,Research Triangle Park: New York,

Zikovelis V. and Tsaparlis G., (2006), Explicit teaching of problem categorisation and a preliminary study of its effect on student performance – the case of problems in colligative properties of ideal solutions, *Chem. Educ. Res. Pract.*, **7**, 114-130.

 This journal is © The Royal Society of Chemistry 2009