

## PART V: DISCUSSION OF ACTIVE LEARNING QUESTIONS

The Active Learning questions are designed for consideration by groups of students in class. Often they work well for introducing a particular topic in class. The purpose of these questions is to give the students the opportunity to discuss their ideas. They also give us as teachers the opportunity to hear these ideas. This is not done solely to get the students to a correct answer for a particular problem, but rather to try to get a better feel for the students' conceptual understandings of the topics we teach in chemistry. Some of these problems have definite answers and some do not. In the discussion in Part V, we will provide you with rationale for the questions, although not always clear-cut answers.

The answers to these questions are not in the *Complete Solutions Guide* for a reason. Simply stated, students tend to look up answers much too quickly, and the point of these questions is not to merely achieve an answer. Therefore, we stress that you emphasize the students' ideas more than just the correct answer; telling the students the answers to these questions is an inefficient way of trying to get them to understand. All of these questions have been used with students at UIUC, and many of the multiple-choice responses have been developed from open-ended questions answered by UIUC students. In addition, many of the multiple-choice questions have been tried with several hundred entering freshmen, and the results will be given in the discussion of the particular questions.

### CHAPTER ONE

- 43,800 minutes
  - 40,320 minutes
  - These are different due to the differences in conversion factors. Answer a could be said to be more "correct" because the conversion factor "4 weeks/1 month" in part b is less exact than those in response a. The problem is useful to show the students that they can get different answers with different conversion factors, and that these conversion factors have an infinite number of significant figures.
- The problem is useful at this point to stress the idea of dimensional analysis and to show the students that they have an intuitive way of dealing with these types of problems, especially if they have a strong understanding of the problem (which almost all of the students will in this case). When you get to Chapter 3, you can go back to this problem and make it an analogy (although a crude one) with chemical stoichiometry; the idea of a limiting "reactant" is also introduced (you can even write out an equation showing  $3P + 2D \rightarrow 4C$ ). The answers are a) 210 pennies, b) 140 dimes, c) 321 g, d) 280 pieces of candy, e)  $2.86 \times 10^3$  g, f) 280 pieces of candy.
- Multiple-choice questions such as this one will be used occasionally, and have proven to be good questions in that the students find explaining away the wrong choices problematic more so than choosing the correct one. Students at this level are generally rather "test savvy" and are quite adept at choosing the right answer; they can even justify it to some extent. However, these choices are the most popular actual student responses to open-ended questions given by chemistry students at UIUC.

Choice c is the best response, although it does not explain why an object that weighs more than an equivalent volume of water would sink. One of the benefits of these types of problems is to let the students know that there can always be a deeper level of an answer. Choice a is a very popular answer, presumably because many students have an intuitive model that an object floats due to being suspended by surface tension (many students will even use the formula  $P = F/A$ , or discuss the use of snowshoes in justifying this answer); this also explains choice d to an extent. Choices b and e are chosen by students either because of a confusion with mass and density, or because the equation for density includes mass and volume. More than stressing the answer, however, is finding what the students think about density and how they use it as an explanatory device. Merely telling them the answer will mean little if they have not had time to think about it and discuss it.

4. For part a, choice iii is the correct choice, in concurrence with the law of conservation of mass. Many students (almost 30% of several hundred incoming freshman tested at UIUC) chose iv or v, indicating that the mass decreased. Some felt that this was due to a “reaction” of some sort, while many believed that in any transfer one would “lose” some of the solution.

For part b, v is the best answer (although iv is reasonable too, especially since the term “somewhat” is rather vague). Almost 40% of the several hundred incoming UIUC students given this problem believed that the volume would remain the same. This introduces the idea that there are “spaces” between molecules.

5. Of several hundred incoming UIUC students, the breakdown for responses for part a was as follows: i. 7%, ii. 40%, iii. 12%, iv. 37%, v. 3%.

Note that the most popular response is that the bubbles are hydrogen and oxygen gases, which makes a response of “chemical change” to part b more reasonable. It seems, then, that if we merely tell the students that the boiling of water is a chemical change, yet they believe that the product is hydrogen and oxygen gases, they will be more confused than they were initially. One of the indicators of a chemical change (with which the students may be familiar) is that a gas is given off, which, from their perspective, is what occurs as water boils.

6. If possible, it might be a good idea to either demonstrate this reaction to the class or have groups of students observe it. Again, students may have good reasons for listing a process as a chemical change or physical change even if they are incorrect. In many ways, their reasons for their answers are more telling than the answers themselves.

In this case, the wax is undergoing both chemical and physical changes as it is both melting and burning. The wick is burning, and is therefore undergoing a chemical change (although it also looks physically different). The glass rod is not really being changed significantly, although it is becoming coated with carbon.

7. This question helps the students to see the limitations of any classification system while at the same time allowing you to get a better idea of how they are using the system. However they classify each substance, it is more important to know which characteristics of a solid, a liquid, and a gas they are using. For example, a bucketful

- of sand takes up the shape of its container, and students may even claim that pudding is relatively compressible. After allowing the students sufficient time to work on this question in groups, you may wish to ask them about toothpaste.
8. Many times students who know the rules of significant figures have difficulty with them in practice and do not realize what it means to limit the precision of a measurement. The answer will be dependent somewhat on how the students read the volume in each of the graduated cylinders. What is important is that they realize that they can be as precise as one-tenth of a milliliter in the left cylinder and to one-hundredth of a milliliter in the right cylinder. Thus, if the student says that the volume of the left cylinder is 3.0 mL and the volume of the right cylinder is 0.31 mL, the total is 3.3 mL. You may wish to have a few more of these problems available for the students to try, and be prepared for the student to be a bit upset because, in their minds “ $3 + .31 = 3.3$ ,” for example. While many of them have intellectualized the rules, actually dealing with a substance such as water will frustrate some students.
  9. Yes, Paracelsus is admonishing his students to learn by observation. Observation of facts is the foundation for all of the other steps in the scientific method.
  10. Experimental results are the facts with which we deal. Theories are our attempt to rationalize those facts. If the experiment is done properly and the theory can't account for the facts, then the theory is wrong. The idea of a model or theory is a major emphasis of this text, and this idea that “theories are truth” seems to be strongly ingrained in students.
  11. If a measurement is not precise, then it may be close to a particular “true” value only by chance. The next measurement may be way off or even the next several may be far from the true value.
  12. Problems such as these are good in that they require the students to decide what information is necessary and how to use this information. Students can often enter numbers into an equation correctly if we give them only the necessary numbers and the equation. However, a problem such as this one requires the student to think about the problem-solving approach that is needed.
  13. Students are often confused about significant figures, and many times even those students who can use them correctly are not sure about the purpose or application. Problems such as these require that the student understand, not merely know, the rules of significant figures, especially with the application to lab measurements.
  14. Mass and volume are often confused or used interchangeably. While both objects will displace the same amount of water, many students will think the lead will displace more water since it is “heavier.” This problem also allows for a discussion of measuring volume by water displacement.
  15. This is a good time to have the students draw molecular-level pictures. The drawings

that the students submit will go much further in letting us know their understanding of the concept than their reciting a text definition.

16. The answer is about 100 feet (95.3 feet), but significant figures are not an issue in this problem.

$$1 \text{ second} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \times \frac{1 \text{ hour}}{60 \text{ minutes}} \times \frac{65 \text{ miles}}{1 \text{ hour}} \times \frac{5280 \text{ feet}}{1 \text{ mile}} = 95.3 \text{ feet}$$

## CHAPTER TWO

1. Over 70% of the several hundred incoming UIUC students correctly chose response e. However, almost 25% of the students chose response d. Again, the largest benefits of a question such as this one are to have the students explain away what they believe to be incorrect explanations and to hear the students' ideas. For example, by choosing d we could believe that the students do not understand an atomic theory. On the other hand, they may simply be confusing the terms "atom" and "element." These types of insights are important for us to make.
2. This question should get the students to start thinking about the conversion between mass and number (which will be useful for the mole concept). One way of solving this problem would be to find the mass of the chalk before and after writing one's name, and find, by subtraction, the mass of chalk it takes to write the name. Then, by knowing the mass of a "chalk molecule," one could calculate the number of "chalk molecules."
3. The main purpose of this question is to get the students to appreciate, in general, the purposes of a model and to consider, more specifically, Thomson's model. The answers to this question will vary from student to student, and it is important here is to stress that the answers are more contingent on their support than on absolute "correctness." However, most students will probably claim in part a that electrons are the most important for the formation of compounds (especially due to Thomson's findings that the electrons are so easily removed). In the case of part c, it is most important to stress that any model that explains Thomson's findings is reasonable, and that this endeavor is what developing models is about; that is, matching observations, not reality. This emphasis on models is extremely important in chemistry and will be further stressed in Chapter 5.
4. When several hundred incoming UIUC students were asked what happens to the size of molecules and to the mass of a sample as ice is heated (until it is steam), about one-third of the students believed that the mass and molecular size varies. Most of these students believed that the mass of the ice is greater than that of the steam, and that the size of the "steam molecules" is greater than that of the "ice molecules." The drawings in conjunction with the explanations can reveal quite a bit about the students' ideas.

5. When several hundred incoming UIUC students were asked this question, almost 40% of the students responded that the mass of this system would decrease, presumably because the chemical has either “disappeared” or has been converted into a gas (which many believed has less mass than the solid). Most of the rest correctly believe that the system ends up with the same mass, although it again is interesting to ask them explain why (especially without using the phrase “law of conservation of mass”).
6. The main goal here is for the students to appreciate the logic of Dalton. Part a is very important, and many students are unaware that they are always making assumptions when solving problems. In this problem their assumptions dictate the rest of their solution. If they assume the simplest formulas (XY, YZ), then the table of masses is  $X = 2$ ,  $Y = 21$ ,  $Z = 15$ . Note that the data of the first experiment do not match that of the third. This discrepancy could be explained if the formula for the first compound is XY and the formula for the third is  $X_3Y$ . If the students decompose 21 g of the compound XY, they would get 1.8 g X and 19 g Y (following significant figures).
7. There should be no difference. It does not matter how a substance is produced, it is still that substance.
8. Yes, many questions are raised from Dalton's theory. For example: What are the masses of the atoms? Are atoms really structureless? What forces hold atoms together in compounds?
9. We now know that some atoms of the same element have different masses. We have had to include the existence of isotopes in our models.
- 11-13. Students all too often memorize rules for naming compounds without understanding that the names are systematic and that the rules are made to be as simple as possible. For example, Roman numerals and prefixes are used only when necessary (that is, if there is more than one possible compound to fit the name, as with “iron oxide” for example). The more we stress the purpose of rules with students, the more they expect there to be a purpose to these rules, and the greater the chance they will achieve understanding.

### CHAPTER THREE

1. As stated in the question, the given choices are actual student responses (incoming students to UIUC). Again, the most important goal of a problem such as this is to get the students talking about why they believe certain responses to be incorrect. Most students will undoubtedly know that d is correct, but many of them will also be surprised that some of the other responses (especially a and e it seems) are not correct.

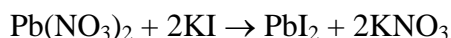
2. The main purpose of this question is to have the students come to the same definitions of what is meant by a formula and what is meant by an equation (many times students will use these terms interchangeably). Also, if the students are more clear about what information is given by a formula (the elements in the compound and the ratio of different atoms in the molecule), they will be more likely to understand what is meant by a balanced equation.
3. This can be thought of as the next step in the chemical stoichiometry analogy (the first step being question 2 from Chapter 1). Many students will be able to do this question correctly, even regarding the limiting reactant portion, yet still claim not to understand other problems (chemical). It is therefore a good idea to make the analogy explicit once the students are successful at this question (which they often are).
4. Even when the students can balance equations and perform limiting reactant calculations, many times they will have difficulty drawing representations of the reactions. In fact, when incoming students at UIUC were given an open-ended question asking them to represent the equation in this question, many of them drew “tri-atomic” hydrogen (presumably because there is a coefficient of three with respect to the hydrogen). In the multiple-choice version given to several hundred students, almost 25% of them chose answers with tri-atomic hydrogen, and only slightly more than half chose the correct response. Their solution should include 4 molecules of ammonia and 4 molecules of diatomic nitrogen.
5. Research on several hundred incoming UIUC students suggests that many of the students will choose “a” from the correct drawing in question number 4 (almost two-thirds chose it). While it simplifies to the correct answer (d) it suggests that perhaps students do not understand what information is being conveyed by a chemical equation. Again, the answer they give is important, but it is perhaps more important to try to understand their reasoning for their answers.
6. This type of problem is good in that it makes the students really think about what they need to know to solve a problem, as opposed to trying to figure out how to “plug and chug” the numbers to arrive at a correct answer. In this case, they need to know the balanced equation, the molar masses of A and B, and the molar mass of the product that is formed. Have the students explain both how they will use the information and why they need the information they claim to need.
7. In this case, only about 10% of the several hundred UIUC students given a multiple-choice version of this type of question correctly chose a response in which the gases had a mass greater than that of the object being burned (because it is becoming an oxide -- or oxides -- of that sample). In fact, about half of the students believed that the mass of the gases would weigh the same as the sample that was being burned (presumably due to the memorized law of conservation of mass).

8. Results from several hundred incoming students at UIUC reveal that about half of the students believed that the mass of an iron bar decreased when it rusts, and almost 25% believed that the mass stayed the same. Less than 20% correctly chose b. Again, it is important in a question like this one to allow the students to discuss their ideas, especially in deciding which choices they believe are incorrect and why.
9. For this question, over one-third of several hundred incoming UIUC students incorrectly believed that the answer to this is “yes.” More important in this case, however, is to get the students to verbalize their explanation.
- 10,11. These questions are related to question 4 from Chapter 1. Only about half of the several hundred incoming UIUC students correctly chose d for question 10. Answer d is the best choice for number 11 (although e is a reasonable choice as well). About half of the students chose d, and 20% chose e. Again, it is important to get at the reasons for the answers, especially since students seem stuck on the law of conservation of mass, although not necessarily in this case. Also, in the case of question 11, over 10% chose a, presumably because more of chemical A (by mass) is involved in the reaction (only about 3% chose b). As with many of the other questions, it is a good idea to use this question to better understand the students' ideas.
12. Many students believe that because the formula for water is  $H_2O$ , a 2:1 mixture of hydrogen and oxygen gases is equivalent to water. Having the students draw molecular-level pictures of the mixture and the compound should help students to relate the macroscopic to the microscopic, which is an important idea in chemistry. This question also gets to the differences between a mixture and a compound.
13. The periodic table shows the average mass of all of the isotopes. Therefore  $^{35}Cl$  must be more abundant because the average mass is closer to 35 than 37. You may also wish to have the students calculate the relative abundance of each of these two isotopes.
14. This question could be followed by a discussion of what average mass means. In this case, a is correct -- no carbon atom has a mass of 12.011.
15. Even students who can balance equations often have difficulty with these questions. The student has to understand why we balance equations, and what the coefficients and subscripts symbolize before they can answer them. After all, a balanced equation is just letters and numbers with an arrow. Its meaning is not intuitively obvious.
16. Many students say 1.0 or 2.0 moles. Some students are uncomfortable with the answer 0.50 mol, presumably because it is a fraction.
17. Students often use the law of conservation of mass inappropriately. It is sometimes a good idea to give the students a question that seems to contradict a known truth. In defending their answer, students come to a deeper understanding of the concepts.

18. The answers are “a” and “c”. Both C<sub>2</sub>H<sub>2</sub> and C<sub>6</sub>H<sub>6</sub> have the empirical formula CH, and NO<sub>2</sub> and N<sub>2</sub>O<sub>4</sub> have the empirical formula NO<sub>2</sub>.

#### CHAPTER FOUR

1. This question is consistent with the many sections that emphasize pictorial representations of ions, molecules, and reactions in solutions, and stems from research that points to the fact that while many students are successful at balancing equations, they are not able to represent these equations. The main point here is to use the students' drawings to get a better idea into their thoughts.
2. When several hundred UI students were given this question, almost 60% correctly stated that the concentration increased. The remaining 40% were about evenly split between claiming the concentration either decreased or stayed the same. This belief presumably came about because the students are not visualizing what is occurring when the water in a solution dissolves and/or because they are using an incorrect definition of concentration.
3. This question is intended to get the students thinking qualitatively (and perhaps semi-quantitatively) about concentration. Again, students are generally good problem solvers in an algorithmic sense, although they do not always consider the concepts in the problems. In this case, there is 3 times as much sugar in solution A as in solution B; the volume of solution A is 1.5 times as great as that of solution B; and the concentration of solution A is 2 times that of solution B.
4. This problem is intended to get the students to consider a representation of a reaction in solution. Given the chemical equation, most of your students can undoubtedly balance this equation, although it is not clear how many students will know what to do when you ask them to draw a representation. The equation is



5. This question allows the student to see that the same element can have many different oxidation states, even without being an ion.
6. Students often want mnemonics (and use some with redox questions). While these may help the student know the “what,” they do little, if anything for the “why.” By gaining electrons, the oxidation state is reduced, because electrons are negatively charged. Thus “gaining” and “reduced” make sense in this context, and one need not rely on a mnemonic device.
7. This question requires the students to understand what the mole-to-mole ratio means. Often students will incorrectly use a coefficient (multiply by the coefficient instead of divide, for example). In this case, the answer is b.
8. This question is another example of having the students use pictures to convey their ideas. These should be accompanied, as always, by an explanation. Look for a

confusion of concentration and volume or concentration and amount of solute. The fact that concentration is a ratio makes it confusing for many students.

## CHAPTER FIVE

1. In this question, the membrane should look concave (pushed into the test tube) in both cases. Even students who believe that the membrane is pushed into the test tube initially sometimes claim that the membrane will “bounce back” unless the syringe is continually pushed down. A good variation with this problem is to use a similar set-up but with the syringe coming from the side, as many students believe that pressure is unidirectional (so that pushing in a syringe from the side will not cause the membrane to be pushed inward).
2. When several hundred incoming students at UIUC were asked this question the breakdown (percentages) for the answers was as follows: 65, 20, 10, 3, 2. Note that only 10% of the students correctly answered this question, although all of these students had at least one year of high school chemistry. Most students believe that there is air inside the tube, and both responses a and b imply that the weight of the mercury is inconsequential (because these responses have the pressures equalizing). Again, the point is not to simply tell the students the correct answer (most of them have undoubtedly heard it) but to allow them to discuss the reasons for their answers so that you can get a better idea of their models. As with other questions, it seems that the most important consideration is to have the students try to explain why they believe that the responses they do not choose are incorrect; they are good at supporting answers that they believe to be correct but find it difficult to explain away other responses. It has proven to be enlightening to ask the students how they would make a barometer (especially with reference to the amount of mercury that is added to the tube).
3. Interestingly, although most students will choose a or b in the previous question, they will, when focused on the amount of mercury in the barometer, claim that the weight does matter (many will have no problem seeing a difference between a mercury barometer and a water barometer). However, they usually have difficulty grasping the idea of pressure as being measured per an area, and, for example, many students will claim that the level of mercury in a tube with a greater circumference will be lower than that in a tube with a smaller circumference. In fact, the level of mercury will be the same in all of the barometers.
4. In this case, the density of a gas will not change if the sample is kept at constant volume, but it will if it is placed in a container fitted with a piston and the temperature is increased (in that case, the density will decrease because an increase in temperature increases the volume). Many students believe that the density of a substance cannot be changed (even after doing calculations of gas density). It would be a good idea to have the students draw pictures of these situations, as emphasized in the chapter.

5. Of several hundred incoming UIUC students given this question, just over half correctly claimed that nothing is between the “dots.” However, almost a third of the students believed that there was either air or oxygen between the air molecules. Again, this shows the need for having the students consider magnified representations of gases (as emphasized in the chapter and in these questions) because while most students can solve problems in which they are to plug numbers into the equation  $PV=nRT$ , almost a third of the students believe that air molecules are located in the space between air molecules.
6. Chemistry majors at UIUC have been asked to discuss this question, and initially most claim that they have done this with straws for years; however, they are hard pressed to explain it, especially when asked to describe this phenomenon by using the kinetic molecular theory. Actual student models that have been proposed include one's finger blocking gravity; and because there is less air in the straw than in the room, there is less pressure in the straw, and the water is pushed up (at the surface they are correct by claiming that there is less pressure, their explanation is incorrect). It might be a good idea to have the materials available (straws and water) so that the students can observe this phenomenon; many notice that a drop (or so) of water comes out of the straw, and some are able to then make the connection that because of this increase in volume of air in the straw (with the same amount of air) the pressure decreases. However, the point is not about telling the students the right answer, but allowing the students to discuss their ideas.
7. Many students are confused by this question and some almost believe that this is proof that Boyle's law doesn't work (in fact, one student claimed that this is true because air is a real gas, and Boyle's law is for ideal gases). It seems that many student use either Boyle's or Charles's law without consideration of the conditions (in this case because more air is added, both pressure and volume can increase, as long as the tire is pliable).
8. It might be a good idea to have the students draw a picture of this situation. By this point they should see the advantages of pictures on their own, but you may have to remind them of it. In this problem, two moles of gas become one mole, and according to the KMT, this gas (XY) should take up half the volume of X and Y separately. Of several hundred incoming UIUC students given this question, almost half (47%) claimed that the volume would not change, and the remaining half were evenly split between the volume increasing and the volume decreasing.
9. The most popular response of several hundred incoming UIUC students to this question is b (about 40%)--that hot air rises. The correct response (d) was chosen by only 20% of the students, and some of them chose it merely because it included the term “density” and they knew this should be part of the answer. Choice e was also popular (23%). Again, the emphasis should be on letting the students discuss their ideas and having them explain why they believe the choices they did not choose are incorrect. This is difficult because all of the responses are correct to some extent. Merely telling the students that the answer is d will not help the students understand

the nature of gases.

10. When several hundred incoming UIUC students were asked this question, only about 27% correctly claimed that the situations would all look the same with a static drawing by merely changing the temperature. The most popular response (42%) was that when cooling the gas the molecules will become significantly closer together. Again, the emphasis is to have the students represent gas molecules and the KMT. In the case of evacuating the gas, most students will draw a picture with fewer gas particles evenly spread (not all pay attention to the detail of the actual number of “dots”), although some leave a lot of open space at the top of the drawing (which makes sense if they think this empty space is air anyway, as cited in question 5).
11. In this case pressure outside the balloon is decreasing, and thus the balloon will expand to equalize pressures. It may be a good idea to compare this question to the barometer question (number 3) in that the students see these situations as similar -- merely an equalizing of pressures.
12. The question is essentially having them explain the ideal gas law, so do not let them use  $PV = nRT$  to explain it. That is, have them explain why  $PV = nRT$  works. The goal is to help them understand the models that we use when dealing with gases.
13. In this question, the main problem is that energy and velocity are not the same. That is, the velocity depends on the mass of the particle as well.
14. Students will often relate pressure to volume or pressure to the amount of gas present without considering the other variables. Once the students have considered this question, ask them to discuss the same situation when the balloon is larger or smaller than the flask.
15. For Dalton’s law of partial pressures to hold true, the simplifications of no interactions among gas particles and negligible particle size must hold true. Have the students explain why.

## CHAPTER SIX

1. Students tend to like questions such as these, which discuss something familiar to them and which can be explained with what they have learned. The key to this question is the differing heat capacities of the different substances. It is important that the students are not allowed to merely say, “because of the heat capacities,” but must explain their ideas.
2. Students have difficulty with this question, and for good reason -- consider that if compound A is lower in energy than compound B, it could be said that the bonds in A are stronger than those in B; thus it takes more energy to break apart something that is lower in energy. This idea is contradictory to some students. The given example (with the hydrogen, oxygen, and water) is one that can be referred to over the course of the semester whenever the phrase “lower in energy” comes up. We have found it helpful

- to have the students observe this reaction so that it is very clear that energy is given off as the reaction proceeds. They can see that the water, because it is formed naturally, is, by definition, lower in energy (and more stable) than the hydrogen and oxygen.
3. The main purpose of this question is to see how the students use these terms in the discussion. Quite a few correct answers are possible, but consistency of terms should be stressed.
  4. If you ask students whether you make ice by putting water in an oven or a freezer they will always get it right (unless they are being sarcastic in response to the ridiculousness of the question). Ask them if the freezing of water is endothermic or exothermic and why, however, and you may be surprised by their responses. Many students initially (and mistakenly) believe this process to be endothermic, and it appears this is the case because ice is cold. Exothermicity is often equated with things blowing up and lots of heat given off, so the students have difficulty accepting this process as an exothermic process. (This, of course, assumes that we take the water to be the system, which is why it is important to listen to the students as they define these terms in context.) As with other questions, merely giving them this answer will probably not suffice in increasing their understanding -- they need to have time and discussion to work through their confusion.
  5. Because we assume the second statement to be the case when doing calculations with calorimeters, many students believe that heat is conserved. This is problematic because assuming heat is conserved reinforces the mistaken idea that heat is a substance.
  6. It may be a good idea to have the students work together on a problem such as this one when it is first introduced. If you decide to have the students work on this question, it is strongly recommended that you have them discuss it in question 7.
    - a)  $w = -7.9 \text{ l. atm}$
    - b)  $w = -9.0 \text{ l. atm}$
    - c)  $w = -9.1 \text{ l. atm}$
  7. Work is not a state function simply because its value is dependent on the pathway. In a one-step expansion, all of the work is done against a relatively small external pressure; in two steps, part of the work is done against a larger pressure. Have the students experiment with their own numbers and they may find that the magnitude of work is maximized in a two-step process when the volume of the first step is exactly in the middle of the initial and final volumes. Even if they do not figure this out, you can tell them and have them try to explain it, which would be a good opportunity to have them make PV diagrams.
  8. If there are fewer forests, then less  $\text{CO}_2$  will be removed from the atmosphere by photosynthesis. The greenhouse effect is a result of increased levels of  $\text{CO}_2$  in the atmosphere and thus will be more severe with forest destruction.

**CHAPTER SEVEN**

1. The purpose of this question is to prompt students to think about the difference between wavelike and particulate properties. It is important for the students to realize that the properties describe the same electron, and perhaps even to realize that the concept of an electron is a model we use.
2. This question is primarily to get the students thinking about what it means for something to be a model, why a model is said to work, and why one would want to abandon an existing model in favor of a new model. In this case, Bohr's model works with hydrogen (and with any one-electron species). In the one-electron cases, it is quite a good model that can predict behavior (although models do not describe reality). Because of the complexities of electron-electron repulsion, however, the model fails to account for other elements.
3. In this problem the students should note that there is a great change between the second and third ionization energies for both elements X and Y. This could indicate that the elements are alkaline earth metals. Because the ionization energies of Y are greater than those of X, element Y should be above X in the periodic table (so, for example, Y could be Mg and X could be Ca). The purpose here is to have the students think about what these numbers mean and how to use the learned trends.
4. Many students think of the first ionization energy for a noble gas as being higher than the second ionization energy because of a memorized rule such as "All elements want to be like noble gases." While this statement is true to an extent, many students misuse it to mean that an atom such as He "really does not want to" lose an electron; however, if it already has, then it is not so difficult to lose the next one. Using this logic, students will also claim that the second ionization energy for an atom such as Mg will actually be negative so that it can be like Ne. Questions 5 and 11 in this chapter and question 5 in the next chapter also get at this idea. Again, the goal here is to prompt the students to elaborate on their ideas.
5. Many students realize that taking a second electron from lithium will be difficult (take quite a bit of energy) because after losing the first electron, the ion will have the same configuration as He. However, as mentioned above, many students will also claim that the second ionization energy for beryllium will be negative (exothermic) because the beryllium ion will "want" to lose another electron to be like He. Do not allow the students to look up the numbers before answering this question (although it might be a good idea to do so after a lengthy discussion) and make sure that the students do not just provide a quick answer (such as "The second IE for Li is greater") but rather explain their reasoning.
6. This question is meant to stress exceptions. Even though these exceptions are explained at length in the book, many time students tend not to give graphs and figures their full attention; whenever you can ask them to explain a figure or graph, it is probably a good idea. This will be especially true in later chapters when some In-

Class Discussion Questions explicitly ask students to explain figures.

7. This question is intended to get the students to think about how to use the trends they have learned. Also, you can get a better idea about what they are thinking in terms of atoms “wanting” to be like noble gases as in questions 4 and 5. Having the students compare their answers to those in the book and then trying to understand the differences can also be enlightening.
8. Students have noticed this trend and are not sure why it exists. In fact, some students have just accepted it as “the way that it is,” which is an attitude that should be dispelled as soon as possible. Questions such as this one, which ask the students to explain something that they may have been merely accepting, are therefore quite educational. Even if we are not sure of the answer, it is a good idea for the students to see that we can make educated hypotheses based on previous information. Students may equate metallic behavior with atomic size and answer accordingly, or you may have to lead them through this concept a bit; whatever the case, allow the students time to discuss their ideas.
9. This question is intended to get the students thinking about the vagueness inherent in the concept of an electron, away from a negatively charged particle with a known orbit.
10. Again, one of the best aspects of a question like this one is that the students are required to explain why they did not choose four of the choices, and, of course, why they did choose a specific answer (not just to choose it but to explain it). In this case, the answer is c, but what is more important at this point is to allow the students the chance to elaborate on their ideas. Once a considerable discussion has taken place, and after choice c is considered as the best answer, this situation serves as another example of Hess' law (depending on when it is covered).
11. As with other questions for this chapter, the goal here is to get to students' ideas about ionization energy when an atom losing an electron is isoelectronic with a noble gas. The most important issue here (as with the other questions) is not to just allow students to answer either “true” or “false” but to explain their ideas. In this case, energy is still required for a potassium atom to lose an electron even though many students will claim that a potassium atom “wants to do this,” and will therefore lose an electron spontaneously (sometimes even claiming that energy is given off).
12. The main reason for this question stems from the observation that many times students merely memorize trends across and down the periodic table or, at best, use a memorized rule as an explanation (such as “there is an increase in electrons”). Thus this question provides a discrepant situation -- if a student uses the “increase in electron” rule as an explanation, this question serves to show the students that this rule has the opposite effects intended. Have the students explain the trends instead of just memorizing them.
13. Students have a notion that we know exactly where the electrons are and that they

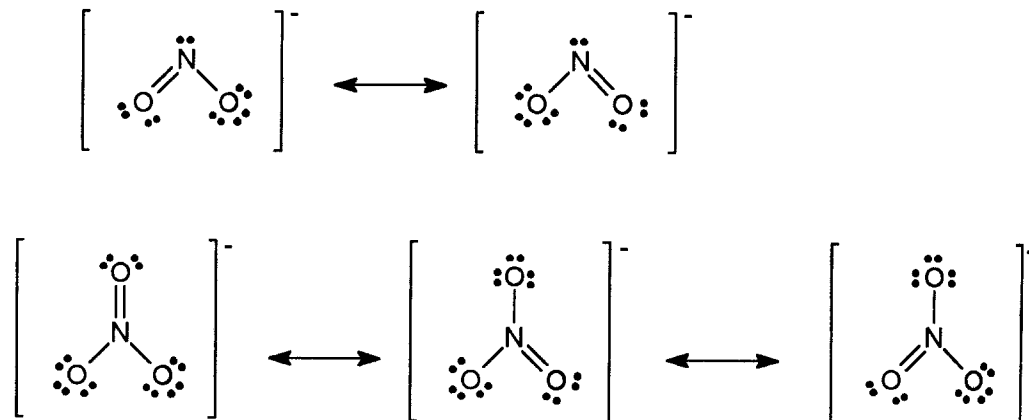
move in predictable orbits. We need to help them accept the idea that our models are based on probability.

14. The term “orbital” is unfortunate in that many students infer a circular orbit from it. However, it represents a region of probability in which one is likely to find an electron. This distinction is crucial.

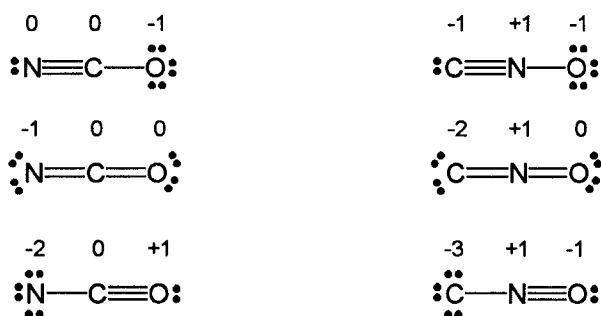
## CHAPTER EIGHT

1. It would be best to have the students answer this question only using a periodic table (without the textbook). Having them understand how these properties are related will decrease the likelihood that students merely memorize the trends.
2. This question allows the students to discuss lattice energy and ionization energy, and to try to understand how to achieve a lowest possible energy state. A discussion of this question may also shed some light on how an alkali metal can “want” to lose an electron, even though the IE is endothermic. Students may be able to do quantitative problems with lattice energy, but they are not always sure what lattice energy means; this problem is meant to get them to apply their definition.
3. As with question 1, have the students answer this question without using the textbook. The goal here is for students to explain their reasoning rather than simply use a catch-phrase. Allow the students to discuss their predictions once they have looked up the answers in the text, as this discussion could provide you with more insight into their ideas.
4. To answer this question, the students should draw Lewis structures of these molecules and note that while the shapes are the same, the atoms (Br versus H) are different. The C-H bond energy is therefore dependent on the environment. The answer reflects the larger electronegativity difference between Br and C than between H and C (the polarity of the bonds makes the C-H bond weaker in  $\text{CHBr}_3$ ). Do not allow the students merely to claim that the answer has to do with electronegativity differences, but have them explain their reasoning.
5. As mentioned in the last chapter, students sometimes believe that the second IE for Mg (for example) will be exothermic because, by losing a second electron, the Mg atom becomes isoelectronic with a noble gas. In this case, many students, consistent with their ideas about the second IEs, will claim that the answer to this question is true, which is not the case. By losing an electron, the positively charged oxygen ion becomes less likely to lose another electron.

6. In drawing the resonance structures, the  $\text{NO}_2^-$  can be thought of as having an average of  $3/2$  bonds, and the  $\text{NO}_3^-$  can be thought of as having  $4/3$  bonds. Thus, the  $\text{NO}_3^-$  has a longer bond length.



7. Drawing the possible structures for these ions, we get (with formal charges):



Given formal charges, the first structure is the best representation for each.

8. No, we would expect the more highly charged ions to have a greater attraction for electrons. Thus the electronegativity of an element does depend on its oxidation state.
9. The electron-electron repulsions are much greater than the attraction of the electron for the nucleus.
10. Instead of just knowing the “what,” the students should also consider the “why?” Many times students will memorize that we sometimes represent a chemical bond as “two shared electrons” but do not consider why this bond forms. A discussion of this issue could help to introduce or reinforce concepts in thermodynamics.
11. Students often memorize the definitions of “ionic” and “covalent” but cannot explain the difference between them. Again, asking the students “why?” instead of “what?” gets to a deeper level of understanding.

12. Many first time students think the answer to this question is “yes” and can “prove” it with simple examples such as water. However, a discussion of this question can get students to see that our models change when atoms come together to form molecules (although a molecular orbital theory is beyond this material, you can set the stage for its later acceptance).

## CHAPTER NINE

1. In having the students answer questions such as this one, it is important to not allow them to merely read the definition from the text but to clearly define the two ideas in their own words. This strategy prompts the students to again think about what is meant by the phrase “lower in energy,” as they did in Chapter 6.
2. Although this concept is discussed in the text, it is a good idea to have three-dimensional models for the students to manipulate as they consider the question. Once the students see the sources of the two pi orbitals and one sigma orbital, a lot of the confusion is lifted.
3. One reason to ask the students this question is to make them more critical readers. That is, they should pay attention to the graphs and figures and not just skip over them. This question is explained in full in Section 9.3 but having the students explain in their own words is a good idea, especially in this case. Students are often more concerned with the product than with the process, and this question (and Section 9.3) emphasizes the process of evaluating a model and making appropriate changes.
4. This question also focuses on the phrase “lower in energy.” Looking at Figure 9.28, if one electron in the sigma 1s molecular orbital was excited to the antibonding orbital, the H<sub>2</sub> molecule would not be energetically more favorable than two separate hydrogen atoms. Although this question is very theoretical, it might be worthwhile to listen to how the students respond.
5. The notion of hybridized orbitals is quite confusing to students, and it is a good idea to have them work together on at least one of these problems.
6. We can determine molecular structures, sometimes directly by X-ray diffraction (Chapter 10). Our view is that if electrons are in orbitals in atoms, then they must be in orbitals in molecules. However, atomic orbitals do not point in the right direction for some molecules. We therefore had to invent the concept of hybrid orbitals. We decide which hybrid orbitals are used once we know the structure. Structures are the facts, and hybrid orbitals come from a model to rationalize these facts.

**CHAPTER TEN**

1. Instead of allowing the students to merely say “because of surface tension” as a complete answer to this question, have the students explain what they mean by surface tension, and even have them draw a magnified view of the water and the soapy water. This approach is consistent with earlier chapters, which stressed pictorial representations of molecules.
2. When several hundred UIUC students given this question, about 40% correctly chose d. However, a, b, and c are all popular (each chosen by about 20% of the students). It is helpful to get an idea about what the students think about physical equilibrium because many times these ideas resurface when they discuss chemical equilibrium. As with other questions, it is more important to listen to how the students defend their choices and critique the other options than to simply tell them the answer.
3. Many students think of the term “boiling point” as meaning the boiling temperature. This question is meant to prompt students to think about how dynamic physical (and eventually, chemical) processes are and about vapor pressure. If possible, it would help for the students to see this process in a class demonstration.
4. Yes, there are some substances in which only dispersion forces are present such as naphthalene,  $C_{10}H_8$ , and polyethylene which are solids at room temperature. The fact that these substances are solids at room temperature tells us that their interparticle forces are stronger than those of substances that are liquids at room temperature, such as water, in which there are hydrogen bonds.
5. The nature of the force stays the same. As the temperature increases and the phase changes, the changes solid  $\rightarrow$  liquid  $\rightarrow$  gas occurs, and a greater fraction of the forces are overcome by the increased thermal (kinetic) energy of the particles.
6. Students have difficulty with explaining what the term “vapor pressure” means, even though it is explained in the text. Make sure that the students explain this idea using their own words. Also, many students do not think of solids as having a vapor pressure.
- 7, 8. Many students will think that vapor pressure decreases over time as the water evaporates (less water means less vapor pressure). Also, some will not realize that the vapor pressure of water at  $100^\circ\text{C}$  is 1.0 atm.
9. The students should be able to explain this idea from their reading in the text, but make sure they explain it in their own words. This discussion will help them to become more active and critical readers.
10. Intramolecular forces will be greater if the molecule melts and boils before it decomposes. This question gets to students’ understandings of these terms, as opposed to just their knowledge of the text definition.

11. This question is similar to the question, “Why do bonds form between atoms?” in that it gets at the “why?” instead of just the “what?” Asking these questions of students (and allowing the students to ask them of us) helps the students become more critical thinkers.

## CHAPTER ELEVEN

1. Again, one reason to ask the students a question like this one is to make them critical readers. While this concept is explained in the book, it is a good idea to listen to the students as they try to explain it in their own words. This edition places an even greater emphasis on representing magnified views of molecules, and it is instructive to have the students be active participants in this process. This question provides a good opportunity to get the students thinking about what the term “equilibrium” means, which will be important in later chapters.
2. This problem is similar to question 1, but a bit more complex. In this case there is a mixture (albeit a small one) of the two liquids, and the vapor pressures eventually become equal such that solutions end up in both beakers. A discussion of a sufficiently theoretical question such as this one can be a good opportunity to better understand how the students are making sense of such concepts as “vapor pressure” and “equilibrium.”
3. The emphasis here is on having the students draw pictures and discuss osmotic pressure in the context of a problem that they have not seen before. The students may know what happens (the freshwater plant shrivels and the saltwater plant expands and possibly bursts), but they probably have not thought about it using the ideas of osmotic pressure.
4. The answer to this question is explained in Section 11.4, but as with some of the other questions it is important to listen to the students as they explain the problem in their own words (especially the reasons why). Many times, but especially in this case, the concepts are quite difficult to understand, and students may have learned to be rather passive readers (and unfortunately many are passive listeners even at the most brilliant of lectures). Therefore it is important to have the students take a more active role as they discuss their ideas with each other.
5. The responses given in the question represent actual student responses when trying to explain freezing-point depression and boiling-point elevations. Interestingly, after discussing this problem for quite some time (over half an hour at times), the students often come to the conclusion that this explanation is as good as any. Finding out what the students like and dislike about this explanation (as opposed to whether they merely agree with it) is important. With an emphasis on vapor pressure, many students will claim that a change in vapor pressure can account for these properties (although the freezing point is still tricky, especially since many students believe that the salt freezes in the water), but when asked why vapor pressure matters, many come back to this explanation.

6. This question is meant to get the students thinking about whether salt freezes in the water, and to see how/if they incorporate the idea of vapor pressure of a solid (ice) in their explanation. The goal here is not to directly tell them an answer, but to try to better determine the ideas they use in their reasoning. This question provides another opportunity to have the students draw their ideas.
7. If the students have already learned about phase diagrams, they can see that water is rather unique in that an increase in pressure can actually cause a solid to liquefy. Thus, if salt is placed on the road and pressure is applied (from a car, from example), the ice could liquefy, salt could go into solution, and the salt-water solution would be less likely to refreeze. However, this response is a rather simplistic answer to a very complex problem and should not be taken as “the answer.” As with the spirit of most of the Active Learning Questions, the goal here is to prompt students to verbalize their ideas.
8. There are many variables in this question, and it is therefore hard to settle on one definite answer (for example, one person may screw the top of the bottle more tightly; if a student suggests this point, it would be best not to simply disregard that suggestion, but to ask “Why would that matter?”). All other things being equal, though, your friend's drink would be more carbonated because of the smaller volume above the drink. Again, have the students explain their answers.

## CHAPTER TWELVE

1. Students have difficulty with the difference between kinetics and thermo-dynamics, and this question is a good way to get them to distinguish between the two. Many times students equate a fast reaction with a thermodynamically stable one (or with one that has a large  $K$  value, or with spontaneity). It is therefore a good idea to have the students differentiate among kinetics, thermodynamics, equilibrium, and spontaneity.
2. The rationale for asking this question is that many times students are not sure how the theory relates to the practice. One would hope that students, after reading the chapter and doing the problems could answer this question, but it doesn't generally seem to be the case. The text provides some examples, and if the students suggest these, have them explain the examples.
3. Students all too often merely memorize Table 12.6 without putting much thought into the conceptual differences among the half-lives. Answering this question allows them to explain reactions of different order and to think about what the term “half-life” means, and why it would differ for different orders of reactions.
4. As the temperature increases, the value for  $k$  should increase, although this increase is not linear. What is most important in this case is to have the students discuss why this is true, and it is up to you to decide how in-depth you wish to go with the Arrhenius equation.

5. As with other questions like this one, it is important to have the students decide what they like and do not like about the statements, especially what they do not like. These statements are actual student statements. While the rate does decrease because of the decreasing concentration of the reactants, the reaction need not “warm up.”
6. The zero order reaction seems odd to many students. While most can do problems with it, many, when asked, admit they do not understand what it means for a reaction to be zero order. The text describes this concept, but the explanation is often missed by the students. As mentioned before, a potential byproduct of asking questions like this one is to inspire the students to become more active readers.
7. Recall from Chapter 3 that students may not be sure what a chemical equation represents, although they can balance the equations. Also, many times rate laws seem to have the same order as they would if taken from the balanced equations. Students are confused by this, especially by the difference between the steps in a mechanism and the balanced equation.
8. In this question, the student should explain why the half-life of zero-order reactions decreases with time, the half-life of first-order reactions is constant, and the half-life of second-order reactions increases over time. In doing so, they should achieve a better understanding of how concentration affects the rate of reaction for each order and what half-life means.

### CHAPTER THIRTEEN

1. These questions were also asked of several hundred incoming UIUC students, and the results were quite interesting. In the case of adding chemical A to the flask, 85% of the students correctly claimed that the concentration of A would be higher once a new equilibrium was established, yet only 55% claimed that the concentration of B would be lower. In fact, 36% claimed that the concentration of B would remain unchanged, making one wonder how the reaction could proceed at all. At least half of the students claimed that the concentrations of C and D would change (most believed they would increase). Many students are confused, when directly asked, by the fact that adding only one reactant causes an increase in the amount of product; “But you are not adding any more B,” they will claim. Also, many students seem to believe that the reactions are unidirectional, even though they will be able to solve the problems. Allow the students ample time to discuss their ideas.
2. Consistent with the increased emphasis on diagrams throughout the fifth edition, this question asks the students to graphically represent the product and is therefore a combination of qualitative and quantitative responses. Again, the goal is to get the students to better understand what is occurring with chemical equilibrium.
3. It may be worthwhile to have the students perform the calculation to check on their answer after discussing what they believe should happen (you would have to provide them with a value for the equilibrium constant, or you could ask them what information they would need to know to solve this problem). When the  $H_2$  is added

- should not matter, but hearing what the students say is important.
- In terms of increasing equilibrium concentrations of D, the answer is ii, i, and iii. In terms of B, the answer is iii, i, and ii. This question goes well with question 1 above.
  - For part a the range should be between 1 and 2 M (closer to 2 as K decreases); for b the range should be between 1 and 3 M (closer to 3 as K decreases); for c the range should be between 1 and 2 M (closer to 2 as K increases); and for d the range should be between 0 and 1 M (closer to 1 as K increases). Students have had quite a bit of difficulty with this one question in the past.
  - As noted in the discussion of question 1, this question has been asked by several students (and probably wondered but left unasked by many others). This question surfaces concepts that these students may be too shy to ask, and allows them the opportunity to discuss it. Having the students draw pictures here would be helpful.
  - Students have believed this statement to be true, indicating that they believe that the most important factor is that K stays constant; that is, they do not necessarily consider the relevant chemistry (such as in question 5). In this case, the amount of C is impossible, but it allows for the “correct” K value. Again, it is important not to just treat this question as a “trick” and quickly tell the students the answer, but to allow them ample opportunity to discuss these issues themselves.
  - Le Châtelier’s principle is an example of a memorized rule that is very overused by the students. These questions allow students to see that an understanding of a concept cannot be achieved merely by memorizing a rule. The pressure is held constant in this problem by allowing the volume to change, which is also a perturbation of the system. This question is quite a complex problem, and you should expect the students to have difficulty with it. Also, if you choose to use this question, allow plenty of time for discussion because it could cause the students to become more confused about equilibrium. However, this potential drawback is outweighed by the potential benefits of having the students realize that it is not their job to memorize rules, but that science is about understanding.

## CHAPTER FOURTEEN

- Many students see the pH of water (or a neutral solution) defined as 7.00 regardless of the temperature and even though the pH scale is explained in the text. Although they read that the pH changes (decreases) as you heat water, they sometimes assume that this statement means that the water is no longer neutral, although it is.
- Strength and concentration are confusing to students and often equated. HCl is always strong but its concentration can vary; along the same lines, ammonia is always weak.
- The first graph seems to pose the more difficult challenge for the students because many claim that as an acid becomes more concentrated, it gives more  $H^+$ , so the

dissociation increases. This is true, but the question asks them to graph percent dissociation, which actually decreases. The text provides an explanation, but this is another concept that the students seem to need to discuss to more fully appreciate. Some students have even used applications of Le Châtelier's Principle in explaining this problem.

4. The purpose of this question is to get the students to think qualitatively about major species and reactions. It is another good problem for which to have them draw pictures. It also provides an opportunity for students to differentiate what is occurring in solution with how they solve these types of problems (for example, many times we have them assume a reaction goes to completion given a sufficiently high value of  $K$ , so students sometimes mistakenly believe that these reactions can go to completion at our will).
5. This question is another example of a problem that has the students qualitatively explain something covered in the text.
6. This question is consistent with the increased emphasis on representing reactions in this fifth edition. With 10 molecules, you must be careful about the  $K$  for HCl and the relatively large value of  $K$  for the weak acid (many students will have 9 of the 10 molecules dissociate). For part D, from strongest to weakest base, the answers are  $A^-$ ,  $H_2O$ , and  $Cl^-$ . Make sure that students explain their answers, even if they are correct.
7. This question is an actual UIUC student question. It has also come up when students are asked to calculate the hydroxide concentration of a solution with a pH less than 7. This question is intended to get at the idea that chemical equilibrium is a dynamic process.
8. Students often confuse the models that we use to think about reactions with the mathematics that we use to solve the problems. Many times we emphasize choice a mathematically, but tell them choice c as a model. It is important to see what they choose, why they choose it, and how they explain away the other choices.
9. This problem is like question 8; that is, it has the students differentiate between math and reality. In this case, the purpose is to have them realize that all reactions are happening at once, but that it is easier to calculate the results by making assumptions. It is up to you to decide whether you would like the students to actually solve the problem. What you may find is that even the students who are able to solve this problem may have difficulty answering these questions. Given the HCl concentration of 0.02 M, the pH would be 5.8.

10. The anion could not be strong, but many students may think that it could be if it comes from a weak acid; that is, often students have memorized the fact that the conjugate base of a weak acid is a strong base. The anion could be amphoteric if it comes from an acid such as phosphoric acid (for example, if the salt is  $\text{NaH}_2\text{PO}_4$ ).
11. This question has confused students even after they have seen a mathematical derivation. Many also use this incorrect relationship. Again, it is important to bring up this idea because many students think it but remain quiet. Have the students actually go through the derivation and explain it.
12. This question is like question 6 in Chapter 3 in that it makes students think about what they need to solve a problem as opposed to trying to figure out how to “plug and chug” the numbers to arrive at a correct answer. One possible answer is that the students must know the dissociation constant values of HX and HY, and the acid with the lower dissociation constant would make the stronger (although still weak) conjugate base, and that salt would have the higher pH.
13. Make sure students explain what pH means in their own terms. The answer to the second part of this question is false (concentration plays a factor).
14. Another “why” question. Students can memorize this number, but they should also have an understanding of its derivation. It can lead to a discussion of the temperature dependence of pH.
15. The answer (yes) is easy enough to prove, but many students instinctively think the answer is no.

## CHAPTER FIFTEEN

1. The fact that the concentration of baking soda does not change the pH should make for a good discussion. Have the students decide on the major reactions; this problem is also intended to get the students to think about major species. It may be a good idea to ask the students to draw pictures here as well. Note that  $\text{HSO}_4^-$  acts essentially exclusively like an acid, although  $\text{HCO}_3^-$  is amphoteric.
2. This question come from actual students and is a good one to ask if for no other reason than to unearth unasked questions. It also gets the students to consider that a buffered solution will change pH and reacts just as they could predict with major species, yet the ratio of conjugate base to acid stays relatively constant. This concept is one reason why the Henderson-Hasselbalch equation should be treated carefully, as students all too often just plug numbers into it with little consideration of the concepts involved. Many times students think of buffered problems as completely different from acid or base problems.
3. As with question 2, this question prompts students to think critically about buffered solutions to the extent of how they work and what makes one better than another. There is an extensive discussion of this idea in the text, but asking the students to

- explain a question such as this should shed some light on the students' ideas, and should help to make the students more critical and more active readers.
4. Another example of asking students to discuss a question discussed in the text.
  5. A good follow-up question to number 4. Students will often memorize how to calculate pH values at various points but not understand why. Give the students the opportunity to consider why the formulas they use work.
  6. Another example of relating theory and practice; it is good practice for the students to try to develop experimental verification on their own. This type of question also allows you to better assess their understanding of  $K_{sp}$ .
  7. Students often become confused about what  $K_{sp}$  values actually measure and how they are related to solubilities. If a  $K_{sp}$  value were zero, it could mean that the solid does not dissolve into ions at all (the product of the ions is zero).
  8. This question represents an addition to question 7 in that many students will equate  $K_{sp}$  values with solubilities such that a higher  $K_{sp}$  necessarily means a greater solubility. While the two are related, it is important for the students to understand that they are not the same thing and to be able to explain why they are different (the number of ions is important in this relationship).
  9. This question is related to both questions 7 and 8. In this case, the students should be asked to explain the underlying theory of this before they start looking up numbers (many of them, if allowed to look up numbers immediately, would be more interested in trying to plug them into an equation somehow than in thinking conceptually about the problem). In its use of  $K_{sp}$  values, though, this is a good introductory problem in having the students calculate solubilities from  $K_{sp}$  values, and in thinking about what solubility means.
  10. In general, the  $K_{sp}$  of a solid will increase with increasing temperature. However, this situation is not always the case and you must decide in how much detail you wish to discuss this issue with your students (the fact that some solids become less soluble with an increase in temperature of the solvent).
  11. Because the sulfide ion comes from a weak acid, the sulfide ion has more affinity for the hydronium ions than does the chloride ion. This being the case, the silver sulfide is much more soluble in an acidic solution than in water. The solubility of silver chloride is not affected. Use this problem to stress the importance of major species and common ions (make the acidic solution be a solution of HCl and ask students to redo the problem), and as an introduction to multiple equilibria.
  12. The students need to understand what is meant by  $K_{sp}$  and  $K_a$  to answer this question. AgY is more soluble in an acidic solution.

**CHAPTER SIXTEEN**

1. In this case, in terms of positional randomness, the forward process (liquid to gas) is favored. In terms of energy randomness, the reverse process is favored (because going from gas to liquid would release energy into the surroundings). This question should prompt the students to differentiate between the surroundings and the system.
2. The change in entropy of evaporation should be larger. As with other questions, have the students explain their answer and use their discussions to better understand their ideas (in this case, specifically about what is meant by  $\Delta S$ ).
3. As mentioned earlier, students have difficulty with the concept of “lower in energy.” In this case, the reaction is exothermic ( $\Delta S_{\text{surr}}$  is positive), but  $\Delta S$  cannot be determined with the given information.
4. Another example of having the students relate theory and practice.
5. This concept is explained in the text, but should be discussed by the students. This question was asked by a student at UIUC, and many other students agreed with him (although it is not a correct statement). It is another example of a problem that should elicit ideas that the students sometimes believe but do not ask.
6. The focus here is on not allowing the students to merely memorize the equations, but to critically think about why the equations are what they are. It is important (and not always obvious to the students) that students recognize the rationale for the equations.

**CHAPTER SEVENTEEN**

1. This question serves as a good introductory problem in that the students should conceptually explain the workings of a cell before doing any calculations. Again, this idea is explained in the text, but this fact does not guarantee that the students are actively reading the explanation. Having them explain figures in the text is a good way of assuring that the students read the book critically.
2. A good follow-up question to question 1, and a good chance for you to better understand the students' ideas. The text explains this idea, although not explicitly. This question requires the students to synthesize a lot of the information that they receive from the text and the lectures.
3. In this case, zinc should be used. This problem requires the students to use Table 17.1 (standard reduction potentials) although this fact is not mentioned in the question. Allow the students some time to figure out what they need to know to solve this problem.
4. Many times students have seen a demonstration in which a penny is placed in nitric acid (it may be a good idea to do this demonstration for the students -- but provide ample ventilation!). Using the values in Table 17.1, the students should be able to figure this answer out, and this problem gives them the opportunity to figure out how

- to use these values (when to reverse the reactions, whether to multiply the potentials, and so forth).
- In this case the voltage should be 0.29 V, and the electrons should flow from the Cr (anode) to the Fe (cathode). The equation is  $3\text{Fe}^{2+} + 2\text{Cr} \rightarrow 3\text{Fe} + 2\text{Cr}^{3+}$ . While there are other, similar end-of-chapter problems, it may be a good idea to have the students work together the first time they attempt such a problem.
  - Some students believe that if  $\text{F}_2$  (for example) is a good oxidizing agent (it is the best one listed in Table 17.1), then  $\text{F}^-$  is a good reducing agent. Just from the data in the table, nothing can be said quantitatively about the reducing potential of the species  $\text{F}^-$  (although we could easily see that  $\text{F}^-$  would not want another electron). The important point here is for the students to realize what they can and cannot tell from the given information.
  - A good follow-up to question 6. We cannot tell anything about  $\text{A}^+$  and  $\text{B}^+$  as reducing agents, but we can say that  $\text{B}^+$  is a better oxidizing agent.
  - This question give you a good opportunity to better understand the students' ideas concerning  $\Delta G$ ,  $w$ , cell potential, and  $Q$ . It also serves as a good introduction to the concept of a concentration cell.
  12. These questions are related ( $\Delta G = -nFE$ ). If the students solve for  $\Delta G$  in question 12, they will see that the first two potentials can be used to calculate the third.
  - This question is a good chance for students to reflect after they have attempted a few calculation problems with galvanic and concentration cells. You may find that even the students who successfully solved the problems are not actively thinking about the issues involved. Stress to the students that by considering these types of questions, they are less likely to need to resort to merely memorize equations.
  - A good follow-up to question 10 (especially to see how the students believe  $E^\circ$  is affected, which it should not be). The cell voltage should be increased by an increase in silver ion concentration and decreased by an increase in zinc ion concentration.

## CHAPTER TWENTY-ONE

- This question is a good introductory problem to introduce to students the ideas of coordination compounds and to have them name these compounds. The formula should be  $\text{K}_2[\text{PtCl}_6]$ , and the name is potassium hexachloroplatinate(IV).
- This question requires the students to use their knowledge to solve a novel problem and synthesize some of the information they have learned. Also, it is not specified precisely in the problem how to go about solving it, so the students have to figure the

procedure out on their own. In both cases, the nickel ion has a charge of +2 thus there are 8 d orbital electrons. The paramagnetic complex is tetrahedral, and the diamagnetic complex is square planar.

3. Both iron ions have a charge of +2 (thus allowing for 6 d orbital electrons). The only difference in this case are the ligands. Because  $\text{H}_2\text{O}$  is more of a weak field ligand than  $\text{CN}^-$ , there is more of a chance that  $\Delta$  is smaller, making  $\text{Fe}(\text{H}_2\text{O})_6^{2+}$  more likely to be paramagnetic. That is not to say that it is paramagnetic, but it is more likely to be paramagnetic. This question requires quite a bit of thinking on the part of the students, and ample time should be given to them to discuss it.
4. In comparing the high-spin case to the low-spin case, you can see that the conditions given in the problem will be satisfied if there are 4 d orbital electrons or 7 d orbital electrons. There can be many answers that satisfy these requirements.