

**INTERMOLECULAR FORCES**

1. (10 points) The following types of intermolecular forces are generally found to be important:
- (a) ion-dipole
  - (b) dipole-dipole
  - (c) hydrogen bonds
  - (d) dipole-induced dipole
  - (e) induced dipole-induced dipole

Decide which type of intermolecular force is most important for each of the following systems.

- (i) Between methane ( $\text{CH}_4$ ) molecules in liquid methane. \_\_\_\_\_
- (ii) Between  $\text{H}_2\text{O}$  and  $\text{CH}_3\text{OH}$  molecules in a mixture of the liquids. \_\_\_\_\_
- (iii) In a solution of  $\text{LiCl}$  in water. \_\_\_\_\_
- (iv) Between  $\text{O}_2$  and  $\text{H}_2\text{O}$  molecules when  $\text{O}_2$  is dissolved in water. \_\_\_\_\_

Which of the above probably involves the weakest interactions? \_\_\_\_\_

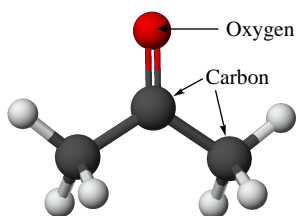
2. (2 points) Rank the following substances in order of increasing boiling point: (a) Ne, (b)  $\text{CH}_3\text{OH}$ , and (c)  $\text{SO}_2$ .

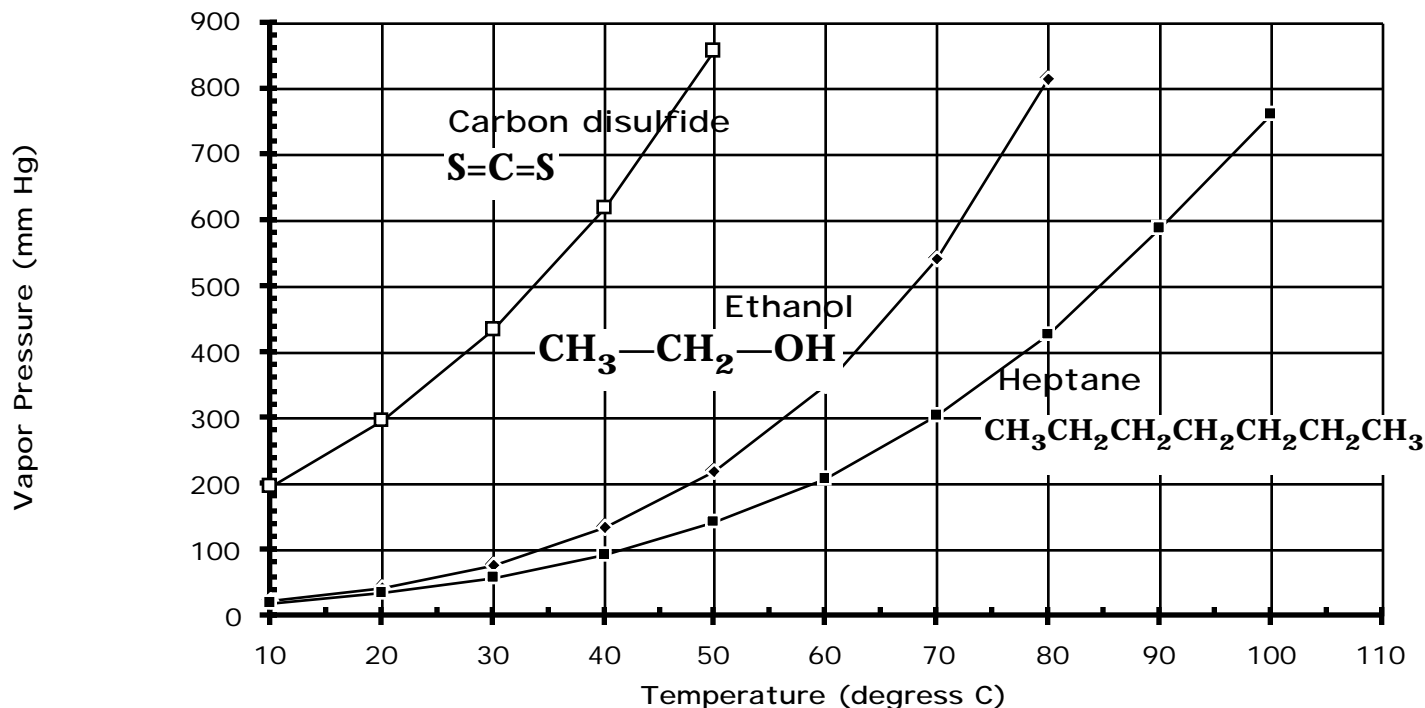
\_\_\_\_\_ lowest boiling point

\_\_\_\_\_

\_\_\_\_\_ highest boiling point

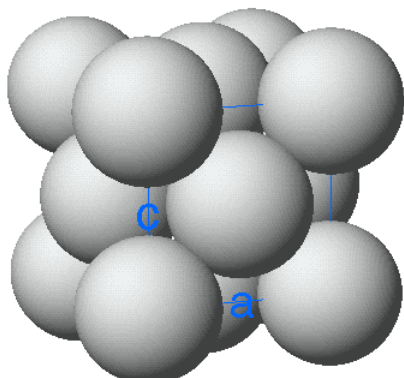
3. (3 points) Acetone,  $(\text{CH}_3)_2\text{C}=\text{O}$ , is a common laboratory solvent. However, it is usually contaminated with water. Why does acetone absorb water so readily? Draw molecular structures showing how water and acetone can interact. What intermolecular force(s) is (are) involved in the interaction?





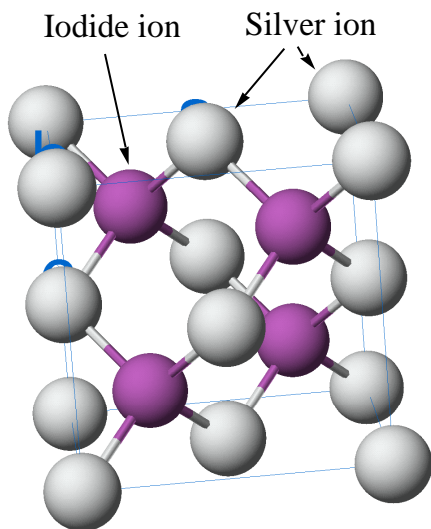
2. (13 points) Use the vapor pressure curves above to answer the following questions:
- What is the vapor pressure of heptane at 70 °C? \_\_\_\_\_
  - What is the normal boiling point of ethanol? \_\_\_\_\_
  - What type of intermolecular force exists (see page 1 for a listing of forces)
    - between two CS<sub>2</sub> molecules? \_\_\_\_\_
    - between two heptane molecules? \_\_\_\_\_
    - between two ethanol molecules? \_\_\_\_\_
  - Suppose the pressure is 600 mm Hg and the temperature is 50 °C. Decide if each substance is a liquid or vapor under those conditions.
    - Carbon disulfide \_\_\_\_\_
    - Ethanol \_\_\_\_\_
    - Heptane \_\_\_\_\_
  - Which one or ones of these molecules is expected to dissolve in water?  
\_\_\_\_\_
  - Explain briefly why the normal boiling point of ethanol is higher than that of CS<sub>2</sub>.
  - Why is the normal boiling point of heptane higher than that of CS<sub>2</sub>?

3. (10 points) Platinum crystallizes in the type of unit cell illustrated here. The radius of a Pt atom is 139 pm. The ultimate goal of the question is to calculate the density of platinum. You can reach that goal by answering parts a, b, and c first. (Recall that  $1 \text{ pm} = 10^{-12} \text{ m}$  or  $10^{-10} \text{ cm}$ )



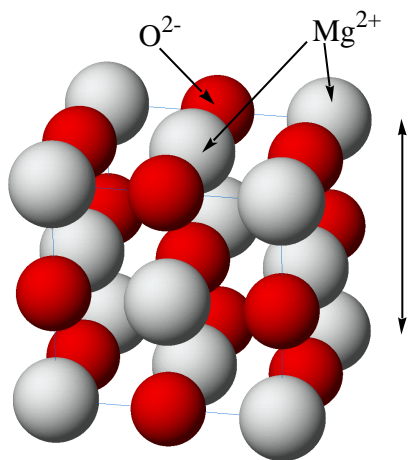
- (a) What is the mass of 1 unit cell of Pt?
- |                                      |                                      |
|--------------------------------------|--------------------------------------|
| 1. $6.642 \times 10^{-24} \text{ g}$ | 3. $3.239 \times 10^{-22} \text{ g}$ |
| 2. $8.098 \times 10^{-23} \text{ g}$ | 4. $1.296 \times 10^{-21} \text{ g}$ |
- (b) What is the length of an edge of the platinum unit cell?
- |   |  |
|---|--|
| 1. $3.932 \times 10^{-8} \text{ cm}^3$  | 3. $1.090 \times 10^{-7} \text{ cm}^3$ |
| 2. $7.772 \times 10^{-12} \text{ cm}^3$ | 4. $5.550 \times 10^{-8} \text{ cm}^3$ |
- (c) What is the volume of 1 unit cell?
- |   |   |
|---|---|
| 1. $3.097 \times 10^{-25} \text{ cm}^3$ | 3. $6.079 \times 10^{-23} \text{ cm}^3$ |
| 2. $1.510 \times 10^{-23} \text{ cm}^3$ | 4. $2.779 \times 10^{-20} \text{ cm}^3$ |
- (d) What is the density of platinum? (**Show your work here!**) (If you do not know how to do the problem to this point, choose one of the answers from the parts above—as needed—and use them to calculate the density.)

4. (3 points) Silver iodide crystallizes in the unit cell shown here.



- (a) How many silver ions are there in each unit cell?  
\_\_\_\_\_
- (b) How many iodide ions are there in each unit cell?  
\_\_\_\_\_
- (c) What is the formula of silver iodide? \_\_\_\_\_

5. (7 points) Magnesium oxide, MgO, has a NaCl-like crystal structure.

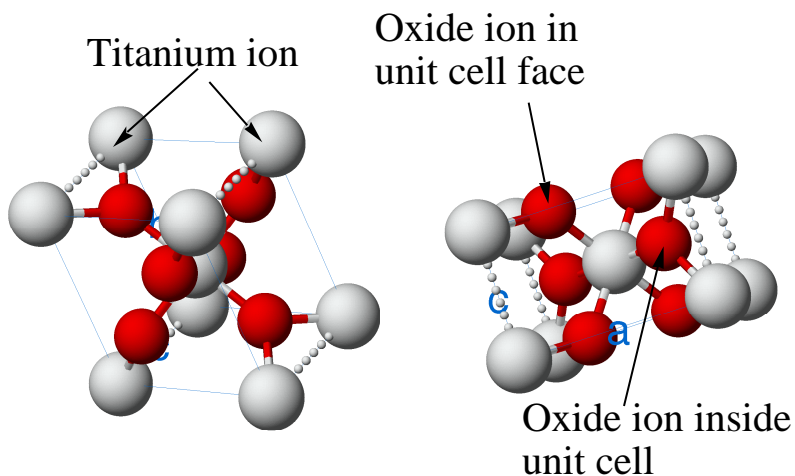


Unit cell edge = (b)  
562.8 pm

- (a) In which type of unit cell are the  $Mg^{2+}$  ions arranged (sc, bcc, fcc)?  
\_\_\_\_\_
- (b) How many magnesium ions are there per unit cell? \_\_\_\_\_

- (c) Calculate the density of magnesium oxide. (Recall that  $1 \text{ pm} = 10^{-8} \text{ cm}$ .) (**Show your work!**)

6. (8 points) Two views of the structure of rutile are shown here.



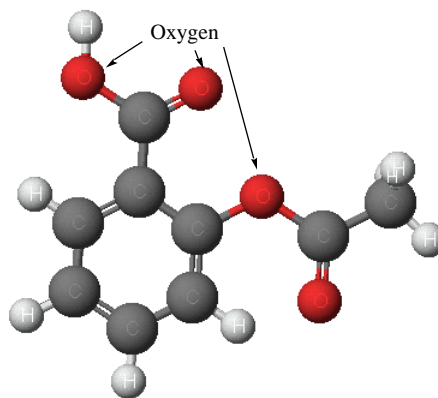
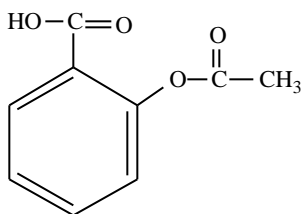
- (a) How many titanium ions are inside the unit cell? \_\_\_\_\_
- (b) How many oxide ions are inside the unit cell? \_\_\_\_\_
- (c) What is the formula of rutile? \_\_\_\_\_
- (d) What is the charge on the titanium ion? \_\_\_\_\_

7. (4) Account for these facts:

- (a) Although ethanol ( $C_2H_5OH$ ) (bp,  $80^\circ C$ ) has a higher molar mass than water (bp,  $100^\circ C$ ), the alcohol has a lower boiling point.
- (b) Mixing 50 mL of ethanol with 50 mL of water produces a solution with a volume slightly less than 100 mL.

8. (3 points) Which of the following compounds would be expected to form intermolecular hydrogen bonds with water?

- (a)  $CH_3OCH_3$  (dimethyl ether)
- (b)  $C_3H_8$  (propane)
- (c)  $CH_3CO_2H$  (acetic acid)
- (d) Aspirin

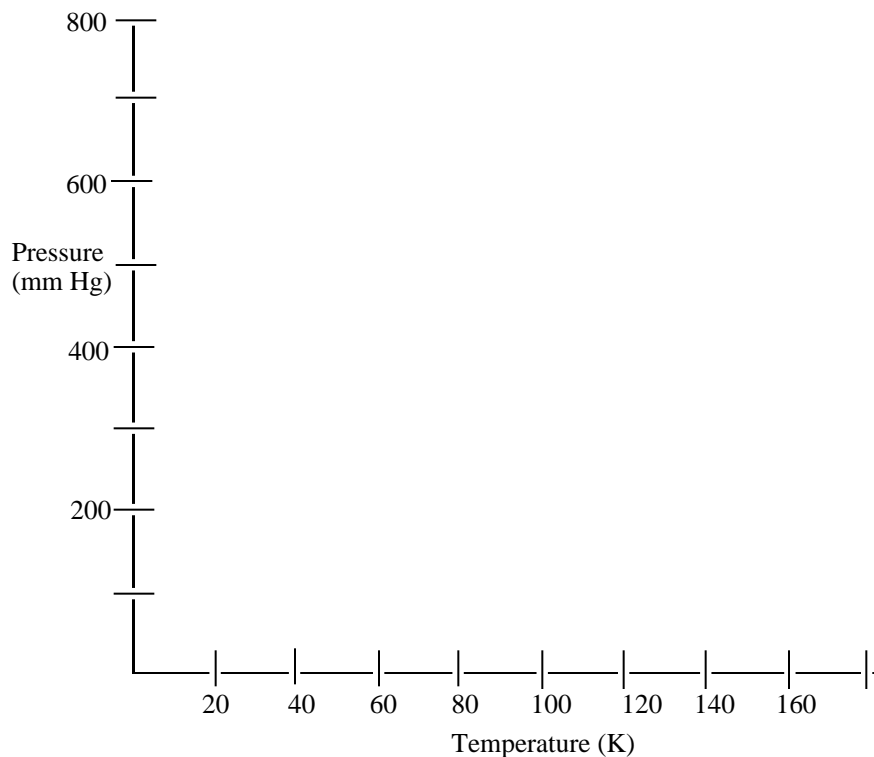


Drawing and model of the structure of aspirin.

9. (5 points) Phase diagram. Using the following information, construct an approximate phase diagram for krypton, Kr:

- normal boiling point = 120.85 K
- normal freezing point = 116.6 K
- triple point = 115.95 K at a pressure of 548 mm Hg

Label these points and the regions appropriate to solid, liquid, and gaseous Kr on your diagram!  
Please draw this as neatly as possible!



Is the density of solid Kr greater or less than the density of liquid Kr? \_\_\_\_\_

**ACID-BASE CHEMISTRY**

1. (6 points) For each of the following cases, decide whether the pH is less than 7, equal to 7, or greater than 7.

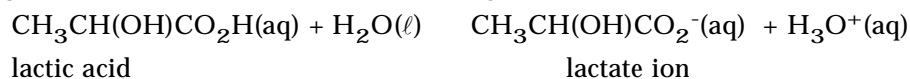
<i>Reaction</i>	<i>pH</i>
Equal volumes of 0.10 M acetic acid, $\text{CH}_3\text{CO}_2\text{H}$ , and 0.10 M KOH are mixed.	_____
25 mL of 0.015 M $\text{NH}_3$ is mixed with 25 mL of 0.015 M HCl	_____
100. mL of 0.0020 M $\text{HNO}_3$ is mixed with 50. mL of 0.0040 M NaOH	_____

2. (3 points) The pH of human blood is controlled by several buffer systems, among them the reaction



Calculate the ratio  $[\text{H}_2\text{PO}_4^-]/[\text{HPO}_4^{2-}]$  in normal blood having a pH of 7.40.

- (a) 0.251  
 (b) 1.56  
 (c) 0.642  
 (d) 3.98  
 (e) None of the above
3. (2 points) During active exercise, lactic acid ( $K_a = 1.4 \times 10^{-4}$ ) is produced in the muscle tissues. At the pH of the body (pH = 7.4), which form will be primarily present: unionized lactic acid  $[\text{CH}_3\text{CH}(\text{OH})\text{CO}_2\text{H}]$  or the lactate ion  $[\text{CH}_3\text{CH}(\text{OH})\text{CO}_2^-]$ ?



Predominant form = \_\_\_\_\_

4. (4 points) If a buffer solution is prepared from 5.15 g of  $\text{NH}_4\text{NO}_3$  (molar mass = 80.043 g/mol) and 0.10 L of 0.15 M  $\text{NH}_3$ , what is the pH of the solution?

- (a) 5.37
- (b) 7.00
- (c) 8.63
- (d) 11.21

What is the new pH if the solution is diluted with pure water to a volume of exactly 500 mL?

\_\_\_\_\_

5. (3 points) Many natural processes can be studied in the laboratory but only in an environment of controlled pH. Which of the following combinations would be the best choice to buffer the pH at approximately 7?

- (a)  $\text{H}_3\text{PO}_4/\text{NaH}_2\text{PO}_4$
- (b)  $\text{NaH}_2\text{PO}_4/\text{Na}_2\text{HPO}_4$
- (c)  $\text{Na}_2\text{HPO}_4/\text{Na}_3\text{PO}_4$

6. (14 points) Acetic acid is a weak acid in water. On the next page you will find a titration curve for the titration of 100 mL of 0.10 M  $\text{CH}_3\text{CO}_2\text{H}$  with 0.10 M NaOH.
- (a) What is the pH of the acetic acid solution before beginning the titration? \_\_\_\_\_
  - (b) Describe the composition of the solution after 50.0 mL of NaOH has been added. What compounds and ions are present in solution?
  
  - (c) What is the pH after 50.0 mL of NaOH has been added? \_\_\_\_\_
  - (d) What species (molecules or ions) are present at the equivalence point?
  
  - (e) What is the total volume of solution at the equivalence point? \_\_\_\_\_ mL
  - (f) Calculate the pH at the equivalence point. (**Show your work!**)