Study Guide for Module 10—Liquids and Solids

Reading Assignment: Chapter 10 in *Chemistry, 6th Edition* by Zumdahl.

Guide for Your Lecturer:

1. *States of Matter (Review)*
2. *Intramolecular and Intermolecular Forces*
3. *Physical Properties of Liquids and Solids*
4. ✔ *Predicting the Properties of Substances from Intermolecular Forces*
5. *Intermediate States: Amorphous Solids and Liquid Crystals*
6. *Types of Crystalline Solids*
7. *Metallic Solids*
8. *Ionic Solids*
9. ✔ *Phase Diagrams*
10. ✔ *Calculating Heat Changes When a Substance is Heated or Cooled*

Homework

Note: ✔ indicates problems to be stressed on drill quizzes and hour exams.

■*States of Matter (Review from Module 1)*

1a) List the three states of matter and give the indicated characteristics of each by completing the following table (p. 26).

-State: _______________ (gas)	-State: _______________ (liquid)	-State: _______________ (solid)
•Shape/Volume: (takes the shape and volume of container)	•Shape/Volume: (takes the shape of container)	•Shape/Volume: (neither shape nor volume changes for container)
•Ability to flow: (flows readily	•Ability to flow: (flows readily	•Ability to flow: (does not flow)
•Compressibility: (easily compressed)	•Compressibility: (hard to compress)	•Compressibility: (hard to compress)

b) Briefly distinguish among gases, liquids, and solids on the basis of each of the following (p. 449)

•Average distance between particles (Particles are usually close together in a solid, a little farther apart in liquid, and widely dispersed in gas)

•The ease with which the particles can move. (Particles in gas move in any direction without hindrance, those in liquid can move around one another but cannot easily escape from liquid, particles in solid cannot move past one another but can only vibrate back and forth)

■*Intramolecular and Intermolecular Forces*

2a) In this module you are studying the factors which determine the physical properties of compounds (i.e. whether the boiling point is high or low, whether the substance flows readily, etc.) In general, what is the major factor which determines these properties? (The forces which must be overcome in order for the atoms, molecules, or ions of a substance to break apart.)

■***Intramolecular and Intermolecular Forces (continued)***

2b) In some compounds, the forces which must be overcome are the bonds which hold the substance together. List and briefly describe the three primary types of bonding in chemical compounds.

-1st type (p. 350) (covalent bonding = bond formed by sharing of electrons)

-2nd type (p. 349) (ionic bonding = bond formed by attraction between oppositely charged ions)

-3rd type (p. 460) (metallic bonding = bond in which "sea of e^-s" are held jointly by metal cations-i.e. a delocalized bond in which valence electrons are shared by all the metal cations)

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c) In most substances which contain covalent bonds, it is not necessary to break the relatively strong covalent bonds in order to separate the particles. Instead, they can be separated by breaking the much weaker "intermolecular" forces. Distinguish between intermolecular and intramolecular forces. ("Intermolecular forces" are between different molecules; "intramolecular forces" are within a given molecule, p. 450)

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d) There are three types of intermolecular forces (sometimes called van der Waal's forces) which might exist between molecules. Briefly describe each of the three. (•1) dipole-dipole forces = attractive forces between polar molecules, •2) induced dipole-induced dipole forces aka London dispersion forces = attraction due to instantaneous dipoles which form as the electrons in an atom or molecule move, •3) H-bonding is the intermolecular interaction between a small, highly electronegative atom such as F, O, or N on one molecule and a hydrogen atom on another molecule. The hydrogen atom must also be covalently attached to a small , highly electronegative atom such as F, O, or N as well.)

•1) dipole-dipole forces

•2) London dispersion (induced dipole-induced dipole forces)

•3) H-bonding

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e) The mere existence of intermolecular forces indicates that one of the postulates of the kinetic molecular theory of gases (p. 212) is wrong.

•What is the postulate which must be wrong? (The postulate which stated "There are no attractive or repulsive forces between particles of a gas unless they collide.")

•Why must it be wrong? (If there were NO forces between gas particles, they would not be able to coalesce to form a liquid.)

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f) What kind of molecules act like dipoles? (those in which the center of "+" and center of "-" do not coincide. In order to be polar, a molecule must a) have polar bonds and b) a shape which doesn't cause polar bonds to cancel out. p. 356-7)

■***Intramolecular and Intermolecular Forces (continued)***

2g) Draw a sketch showing dipole-dipole forces between two molecules.

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h) Draw a sketch showing London dispersion forces between two molecules. (See Figure 10.5 on page 453.)

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i) Draw a sketch showing H-bonding between two molecules of water.

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j) What kind of atom must be in a molecule for the molecule to exhibit hydrogen bonding? (It must contain a small , highly electronegative atom such as F, O, or N.)

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k) Hydrogen-bonding also helps chemists to explain other anomalous behavior of water such as the fact that ice floats in liquid water at $0^{o}C$ whereas most solids sink in their respective liquids at the melting point, the fact that the heat of vaporization of water is much higher than expected when compared to similar compounds, etc. Explain why ice floats in water at $0^{o}C$. (The particles in a liquid are usually farther apart than in the corresponding solid because more room is needed for particles to move past one another as in a liquid than to vibrate as in a solid. In water, however, the molecules are farther apart in the solid because they can form more H-bonds if they move apart when freezing.)

■***Intramolecular and Intermolecular Forces (continued)***

2l) **Rules for determining the relative strength of forces which must be overcome to separate the particles of a substance.**

1) *It is always necessary to break the strong ionic bonds to separate the ions in an ionic substance. Therefore, ionic substances always have high melting points, high boiling points, etc.*
2) *In most covalent substances, it is only necessary to break weak intermolecular forces (not strong covalent bonds) to separate molecules. Therefore, most covalent substances have relatively low melting points, boiling points, etc. To determine which of a series of molecules has the stronger force*
   a) *When molecules have roughly the same molecular weights and shapes, the more polar molecules have the stronger forces because London dispersion forces are roughly equal.*
   b) *When molecules differ greatly in molecular weight, the heavier molecules (those with the most electrons) have the stronger forces because London dispersion forces usually contribute more to forces than does dipole-dipole attraction.*
   c) *Molecules in which H-bonding exists (i.e. those in which a H atom is bonded directly to a small electronegative element such as F, O, or N) always have stronger forces than similar molecules without H-bonding.*

S. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (These are noble gases which exist as individual atoms. The only forces present between the atoms are dispersion forces. Therefore, the rule which applies is “2b-The greater the molecular (or atomic) weight, the stronger the forces and hence the higher the boiling point. See p. 455)

Atom	He	Ne	Ar	Kr	Xe
# e^-'s	2	10	18	36	54
bp	-269^{o}C	-246^{o}C	-186^{o}C	-133^{o}C	-108^{o}C

A. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (These are diatomic nonpolar molecules held together with covalent bonds. The only forces present between the molecules are dispersion forces. Therefore, the rule which applies is “2b-The greater the molecular weight, the stronger the forces and hence the higher the boiling point.)

Atom	F_2	Cl_2	Br_2	I_2
# e^-'s	18	34	70	106
bp	-188^{o}C	-34^{o}C	59^{o}C	184^{o}C

B. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (These are diatomic polar molecules held together with covalent bonds. Because they are polar there are both dipole-dipole interactions and London dispersion forces between the molecules. Therefore, the rule which applies is “2b-The greater the molecular weight, the stronger the forces and hence the higher the boiling point.)

Molecule	HCl	HBr	HI
# e^-'s	18	36	54
bp	-85^{o}C	-67^{o}C	-35^{o}C

C. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (These are polar molecules held together with covalent bonds. Because they are polar there are both dipole-dipole interactions and London dispersion forces between the molecules. Therefore, the rule which applies is “2b-The greater the molecular weight, the stronger the forces and hence the higher the boiling point.)

Molecule	H_2S	H_2Se	H_2Te
#e^-s	10	36	54
bp	-61^{o}C	-42^{o}C	-2^{o}C

■***Intramolecular and Intermolecular Forces (continued)***

2l) D. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (All four are polar molecules held together with covalent bonds. Because they are polar there are both dipole-dipole interactions and London dispersion forces between the molecules. IN ADDITION, H_2O has H-bonding. Therefore, the rule for H_2S, H_2Se, and H_2Te is "2b-The greater the molecular weight, the stronger the forces and hence the higher the boiling point. The boiling point of H_2O is much higher because it has H-bonding so the rule for it is "2c-Molecules in which H-bonding exists always have stronger forces than similar molecules without H-bonding.)

Molecule	H_2O	H_2S	H_2Se	H_2Te
#e^-s	10	18	36	54
bp	100^oC	-61^oC	-42^oC	-2^oC

E. Which of the above rules best explains why the boiling points of the following vary as indicated? Provide detail. (All four are diatomic polar molecules held together with covalent bonds. Because they are polar there are both dipole-dipole interactions and London dispersion forces between the molecules. IN ADDITION, HF has H-bonding. Therefore, the rule for HCl, HBr, and HI is "2b-The greater the molecular weight, the stronger the forces and hence the higher the boiling point. The boiling point of HF is much higher because it has H-bonding so the rule for it is "2c-Molecules in which H-bonding exists always have stronger forces than similar molecules without H-bonding.)

Molecule	HF	HCl	HBr	HI
#e^-s	10	18	36	54
bp	20^oC	-85^oC	-67^oC	-35^oC

■***Physical Properties of Liquids and Solids***

3. In the previous learning goal you considered the relationship between the magnitude of intermolecular forces within a number of substances and the relative boiling point of those substances. We will now consider other physical properties which are related to the size of the intermolecular forces between molecules.

a) Define capillary action (The spontaneous rising of a liquid in a narrow tube. p. 454)

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b) Distinguish between cohesive and adhesive forces. (cohesive forces = intermolecular forces among molecules, adhesive forces = forces between liquid and the container, p. 455)

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c) Explain what causes capillary action. (Liquids such as water which have both strong cohesive forces which hold molecules together and strong adhesive forces between water and glass container exhibit appreciable capillary action. Molecules which touch the glass are pulled up the surface by adhesive forces. Cohesive forces pull other water molecules up as well. p. 454-5)

■*Physical Properties of Liquids and Solids (continued)*

3d) Briefly define each of the following physical properties of liquids or solids and state how each varies as forces between molecules increases.

Property	Definition	Variation as forces increase
vapor pressure (p. 484-5)	(Pressure exerted by a vapor in equilibrium with its liquid in a closed container.)	
melting point (p. 491)	(Temperature at which a solid changes into a liquid.)	
boiling point (p. 491)	(Temperature at which the vapor pressure of a liquid equals the external pressure applied to it.)	
surface tension (p. 454)	(A measure of the tendency of molecules on the surface of a liquid to be pulled back into the liquid.)	
viscosity (p. 454)	(A measure of the resistance of a liquid to flow. Honey is more viscous than water. Viscosity usually decreases as temperature increases.)	
heat of fusion (p. 489)	(Enthalpy required to cause a given amount of a substance, usually a mole, to change from the solid to liquid state.)	
heat of vaporization (p. 483)	(Enthalpy required to cause a given amount of a substance, usually a mole, to change from the liquid to gaseous state.)	

✔✔✔■*Predicting the Properties of Substances from Intermolecular Forces*

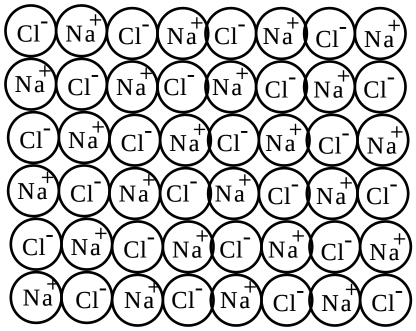
4a) If you had to break the indicated forces, which of the following substances would have the higher indicated property.

Forces broken in Substance 1	Forces broken in Substance 2	Substance which has the higher indicated property: Boiling Point	Melting Point	Vapor Pressure	Surface Tension	Viscosity
ionic bonds	dipole-dipole					
H-bonding + London Dis.	London Dis. (similar cmpds)					
London Dis. (45 e⁻'s)	London Dis. (20 e⁻'s)					
London Dis.	ionic bonds					

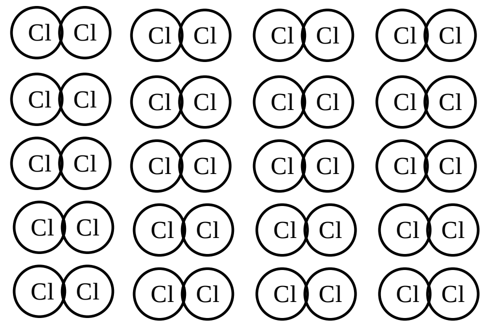
✔✔✔■*Predicting the Properties of Substances from Intermolecular Forces (continued)*

4b) The bond holding the sodium and chloride ions together in sodium chloride is approximately the same strength as the bond holding the two chlorine atoms in Cl_2. Use the following pictorial representations of NaCl and Cl_2 to explain why sodium chloride has a very high melting point whereas Cl_2 has a low one.

NaCl:



Cl_2:



c) Define electronegativity. (p. 352)

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d) State the general variation in electronegativity in the periodic table. (p. 353)

-1) Variation in a row

-2) Variation in a group

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e) List the four most electronegative elements in order of increasing electronegativity. ($N \approx Cl < O < F$)

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f) What is the electronegativity of H? (About the same as that of C.)

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g) Predict the relative magnitude of the physical property indicated.

S.

	NaF	F_2
Type of Bonding	Ionic since metal + nonmetal	Covalent since two nonmetals
Forces which must be be broken to separate liq or solid particles.	Strong ionic bonds	London dispersion forces

Which has higher boiling point, NaF or F_2? Explain your answer.

NaF has a much higher boiling point than F_2 because the strong ionic bonds are much harder to break than are the London dispersion forces. Therefore, NaF must be heated to a very high temperature before the ions obtain enough kinetic energy to break out of the solid state. The molecules in solid F_2, however, have enough kinetic energy to break out of the solid at a much lower temperature since the forces between the molecules are very weak.

A.

	$CaCl_2$	Cl_2
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the higher vapor pressure, $CaCl_2$ or Cl_2? Explain your answer.

✔✔✔■Predicting the Properties of Substances from Intermolecular Forces (continued)

4g) Predict the relative magnitude of the physical property indicated.

B.

	Br_2	I_2
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the lower viscosity when a liquid at the same temperature, Br_2 or I_2? Explain your answer.

C.

	PCl_3	$AsCl_3$
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the lower melting point, PCl_3 or $AsCl_3$? Explain your answer.

D.

	CH_3CH_2OH	CH_3CH_2SH
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the lower melting point, CH_3CH_2OH or CH_3CH_2SH? Explain your answer.

E.

	$CH_3CH_2CH_2CH_3$	CH_3CH_3
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the lower surface tension, $CH_3CH_2CH_2CH_3$ or CH_3CH_3? Explain your answer.

✔✔✔■Predicting the Properties of Substances from Intermolecular Forces (continued)

4g) Predict the relative magnitude of the physical property indicated.

F.

	NaF	SCl_2
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the higher viscosity, NaF or SCl_2 ? Explain your answer.

G.

	$CH_3CH_2CH_3$	CH_3CHO
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has higher melting point, $CH_3CH_2CH_3$ or CH_3CHO? Explain your answer.

H.

	CH_3CH_2F	CH_3CH_2Br
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has the higher vapor pressure, CH_3CH_2F or CH_3CH_2Br ? Explain your answer.

I.

	KCl	CCl_4
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has higher boiling point, KCl or CCl_4? Explain your answer.

✔✔✔■*Predicting the Properties of Substances from Intermolecular Forces (continued)*

4g) Predict the relative magnitude of the physical property indicated.

J.	HF	HCl
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has higher surface tension, HF or HCl Explain your answer.

K.

	$CH_3CH_2CH_2CH_3$	$CH_3CH_2CH_2F$
Type of Bonding		
Forces which must be be broken to separate liq or solid particles.		

Which has higher melting point, $CH_3CH_2CH_2CH_3$ or $CH_3CH_2CH_2F$? Explain your answer.

■*Intermediate States: Amorphous Solids and Liquid Crystals*

5a) Distinguish between amorphous and crystalline solids. (In crystalline solids, the particles are arranged in a regular way in three dimensions. In an amorphous solid, there is considerable disorder similar to that present in a liquid. p. 456)

b) List two common types of amorphous solids. (glass, rubber, plastics, etc.)

c) State two ways of distinguishing an amorphous solid from a crystalline one. (1: Try to melt the solid. If it melts at a specific temperature, it is crystalline. If it merely gets softer and softer as it gets hotter and hotter, it is amorphous. 2: Break the solid. If it is crystalline, it will tend to break with smooth edges. If it is amorphous, the edges of the break will tend to be jagged.)

-1)

-2)

■***Types of Crystalline Solids***

6a) List the five general types of crystalline solids, the major type of force which holds each together, and relative physical properties of each by completing the following table.

Type of crystalline solid	The major type of force holding the particles together in the solid	mp of solid	hardness	Examples
-1) *covalent network*	*covalent bonds*	*very high*	*very hard*	*diamond* *sand (SiO_2)*
-2) *metallic*	*metallic bonds*	*moderate to high*	*moderate to very hard*	*any metal or alloy*
-3) *atomic*	*induced dipole-induced dipole*	*very low*	*soft*	*He, Ne, Ar*
-4) *molecular*	*covalent bonds within molecule* *intermolecular forces between molecules*	*low*	*soft*	*ice (H_2O)* *dry ice (CO_2)*
-5) *ionic*	*ionic bonds*	*high*	*hard*	*NaCl, KI*

b) What is the general principle which determines how the atoms of a metal pack? (Metal atoms pack together as closely as possible i.e. So that each metal atom has the maximum number of atoms close to it. p. 461)

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c) Explain why substances held together by metallic bonding are ductile and malleable whereas other compounds are not. (In most compounds, one must break the bonds to deform a solid. In metallic substances, however, it is possible to move atoms past one another-i.e. to deform the substance-without breaking the bond because metal atoms are held together by delocalized valence electrons. p. 460)

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d) Explain why substances held together by metallic bonding conduct heat and electricity well whereas other compounds do not. (Delocalized e^-'s in metals readily move throughout the metal making it easy to transfer kinetic energy and/or electrical current.)

✔✔✔■*Phase Diagrams*

7a) Define vapor pressure. (p. 484-85)

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b) Define melting point. (p. 491)

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c) Define boiling point. (p. 491)

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d) Define •critical temperature (The highest temperature at which a substance can exist as liquid. p. 494)

•critical pressure (The pressure which must be applied to cause a gas to liquefy at its critical temperature. p. 494)

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e) Define triple point. (The temperature and pressure at which gas, liquid, and solid are all in equilibrium. pp. 493)

7f) S. Answer the indicated questions about the given phase diagrams. (pp. 493-500)

a) What is the normal boiling point of the substance?
≈82°C

b) What is the boiling point of the substance at 500 torr?
≈70°C

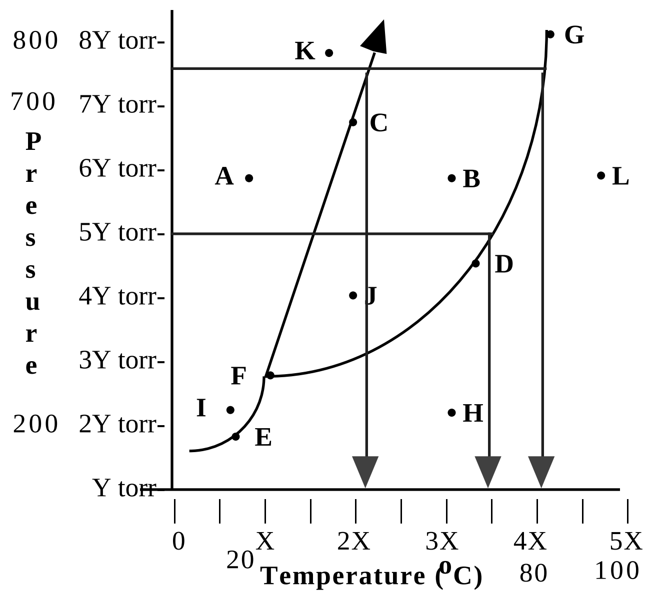
c) What is the triple point of the substance?
≈21°C and 280 torr

d) What is the normal melting point of the substance?
≈42°C

e) What is the critical point of the substance?
≈84°C and 810 torr

f) What happens to the substance if it is transformed from point B to H.
It changes from a liquid to a gas as pressure is lowered and temperature is kept constant.

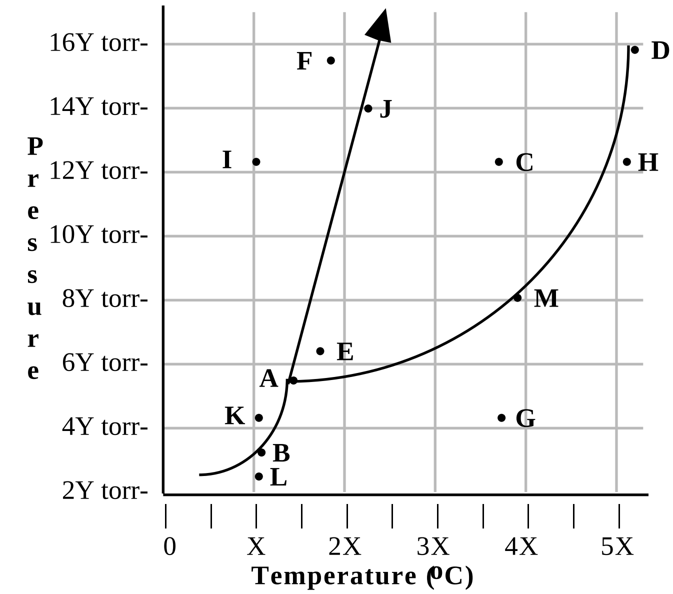
Note: Y = 100 and X = 20 in the diagram below.



✔✔✔■Phase Diagrams (Continued)

7f) A. Answer the indicated questions about the given phase diagrams. (pp. 492-7)

Note: Y = 50 and X = 50 in the diagram below.



a) What is the normal boiling point of the substance?

b) What is the boiling point of the substance at 600 torr?

c) What is the triple point of the substance?

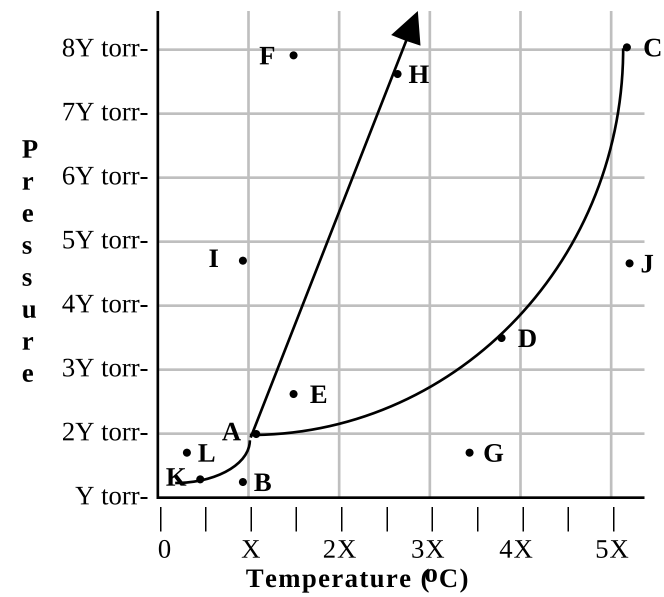
d) What is the normal melting point of the substance?

e) What is the critical point of the substance?

f) What happens to the substance if it is transformed from point G to C.

B. Answer the indicated questions about the given phase diagrams. (pp. 493-500)

Note: Y = 100 and X = 100 in the diagram below.



a) What is the normal boiling point of the substance?

b) What is the boiling point of the substance at 400 torr?

c) What is the triple point of the substance?

d) What is the normal melting point of the substance?

e) What is the critical point of the substance?

f) What happens to the substance if it is transformed from point L to G.

✔✔✔■Phase Diagrams (Continued)

7f) C. Answer the indicated questions about the given phase diagrams. (pp. 492-7)

Note: Y = 100 and X = 10 in the diagram below.

a) What is the normal boiling point of the substance?

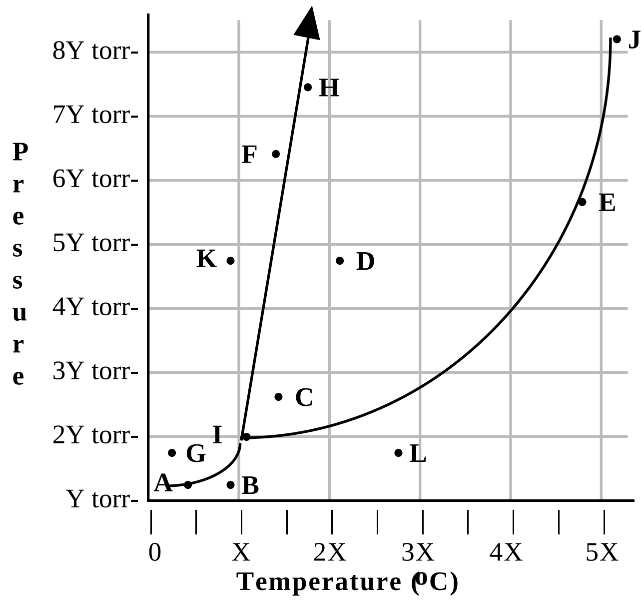
b) What is the boiling point of the substance at 500 torr?

c) What is the triple point of the substance?

d) What is the normal melting point of the substance?

e) What is the critical point of the substance?

f) What happens to the substance if it is transformed from point L to G.



D. Answer the indicated questions about the given phase diagrams. (pp. 493-500)

Note: Y = 200 and X = 100 in the diagram below.

a) What is the normal boiling point of the substance?

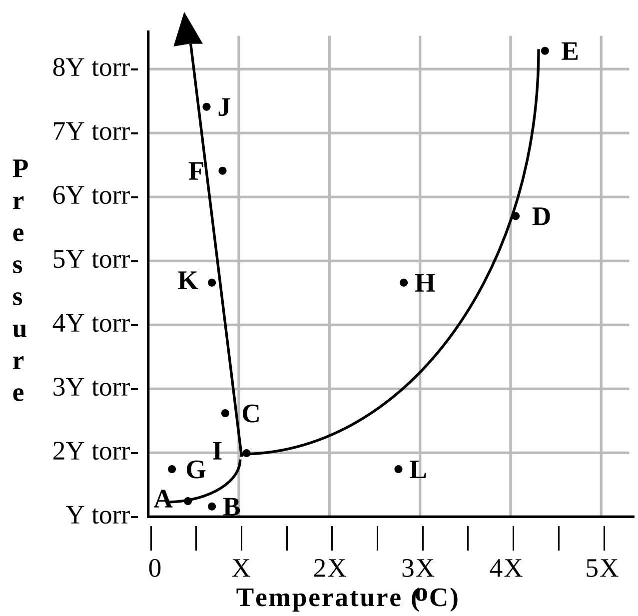
b) What is the boiling point of the substance at 600 torr?

c) What is the triple point of the substance?

d) What is the normal melting point of the substance?

e) What is the critical point of the substance?

f) What happens to the substance if it is transformed from point F to C.



✔✔✔■*Phase Diagrams (Continued)*

7f) E. Answer the indicated questions about the given phase diagrams. (pp. 492-7)

Note: Y = 200 and X = 200 in the diagram below.

a) What is the normal boiling point of the substance?

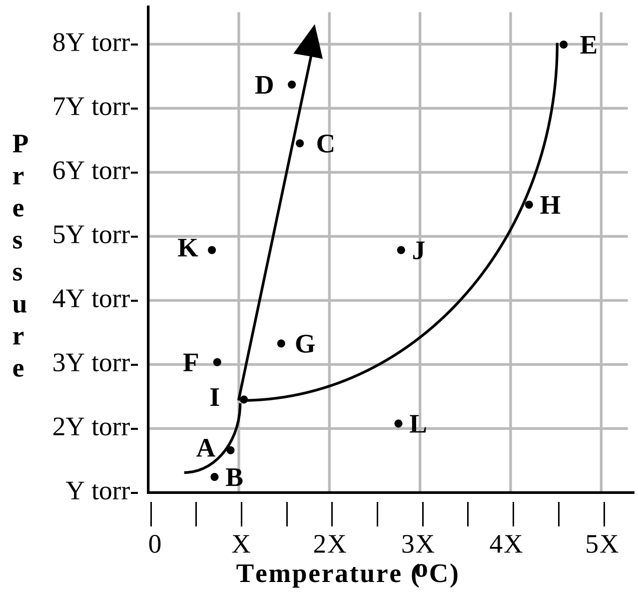
b) What is the boiling point of the substance at 1200 torr?

c) What is the triple point of the substance?

d) What is the normal melting point of the substance?

e) What is the critical point of the substance?

f) What happens to the substance if it is transformed from point K to J.



✔✔✔■*Calculating ΔH when a Substance is Heated or Cooled without a Phase Change (Review fromModule 6)*

8a) Use your General Chemistry datasheet to fill in the following values:

• the heat capacity of ice ____________________ • the heat capacity of water _____________________

• the heat capacity of steam _________________

8b) S. Calculate the enthalpy change when 25.0 grams of ice at -23°C is heated to -5°C.

$$\Delta H = C_p * amt * \Delta T = \frac{2.092\ J}{\cancel{g\ ^oC}} * 25.0\ \cancel{g\ water} * (-5.0\ \cancel{^oC} - (-23.0)\ \cancel{^oC}) = 941.4\ J = 941\ J$$

A. Calculate the enthalpy change when 123 grams of steam at 187°C is cooled to 135°C.

B. Calculate the enthalpy change when 87.6 grams of water at 57°C is heated to 95°C.

✔✔✔■*Calculating ΔH when a Substance is Heated or Cooled without a Phase Change (cont'd)*

C. Calculate the enthalpy change when 42.7 grams of ice at -37.0^{o}C is heated to -15.0^{o}C.

D. Calculate the enthalpy change when 19.4 grams of steam at 153^{o}C is heated to 195^{o}C.

E. Calculate the enthalpy change when 142 grams of ice at -7.0^{o}C is cooled to -32.0^{o}C.

F. Calculate the enthalpy change when 115 grams of water at 43.2^{o}C is heated to 67.4^{o}C.

✔✔✔■*Calculating ΔH when a Substance Changes State (Review fromModule 6)*

9a) Use your General Chemistry datasheet to fill in the following table:

the amount of heat required to convert one mole of water from the solid state to the liquid state at 0^{o}C	
the amount of heat required to convert one mole of water from the liquid state to the solid state at 0^{o}C	
the amount of heat required to convert one mole of water from the liquid state to the gaseous state at 100^{o}C	
the amount of heat required to convert one mole of water from the gaseous state to the liquid state at 100^{o}C	

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b) S. Calculate the enthalpy change when 25.0 grams of ice melts at 0^{o}C.

$$\Delta H = \Delta H_{\text{phase transition}} * \text{amt} =$$

$$\Delta H = \Delta H_{\text{fusion}} * \text{amt} = \frac{6.02\ \cancel{kJ}}{\cancel{mole}} * 25.0\ \cancel{\text{g water}} * \frac{1\ \cancel{\text{mole water}}}{18.02\ \cancel{\text{g water}}}$$

R

$$= 8.351\ kJ = 8.35\ kJ$$

A. Calculate the enthalpy change when 123 grams of steam condenses at 100^{o}C.

✔✔✔■*Calculating ΔH when a Substance Changes State (continued)*

B. Calculate the enthalpy change when 87.6 grams of water freezes at 0°C.

C. Calculate the enthalpy change when 42.7 grams of ice melts at 0°C.

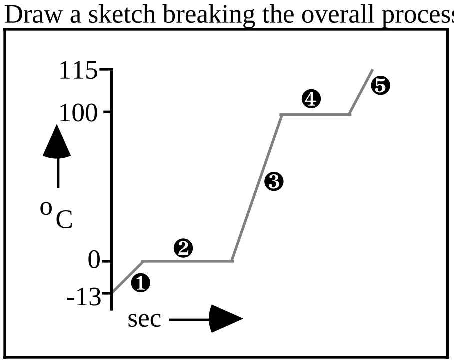
D. Calculate the enthalpy change when 19.4 grams of water vaporizes at 100°C.

✔✔✔■*Calculating ΔH when a Substance is Heated or Cooled*

10. In this learning goal we consider enthalpy changes when the substance is both heated (or cooled) and undergoes a change in state. To work such problems you merely divide the overall process into steps in which the substance is either being heated (or cooled) or in which it undergoes a change of state, calculate ΔH for each step, and then add the steps together (Hess' Law) to get the overall enthalpy change.

    Calculate the enthalpy change for the following processes using this procedure. (p. 489)

S. 25 grams of ice at -13°C is changed into steam at 115°C.
   a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.



❶The ice is heated from -13°C to 0°C.
❷The ice is melted at 0°C.
❸The liquid water is heated from 0°C to 100°C.
❹The liquid is vaporized from 100°C.
❺The steam is heated from 100°C to 115°C.

b) Calculate the heat change for the overall process.
Calculate the ΔH for each of the steps in part a.

❶heating ice = $\Delta H_1 = C_{ice}$*amt*ΔT = (2.092 J/~~g°C~~)(25 ~~g~~)(0~~°C~~-(-13~~°C~~)) = 6.80 x 10^2 J

❷melting ice = $\Delta H_2 = \Delta H_{fus}$*amt = (6.02 ~~kJ~~/~~mol~~)(25 ~~g~~)(1 ~~mol~~/18.02 ~~g~~)(1000 J/1 kJ) = 8.35 x 10^3 J

❸heating water = $\Delta H_3 = C_{water}$*amt*ΔT = (4.184 J/~~g°C~~)(25 ~~g~~)(100~~°C~~-0~~°C~~) = 1.05 x 10^4 J

❹vaporizing = $\Delta H_4 = \Delta H_{vap}$*amt = (40.67 ~~kJ~~/~~mol~~)(25 ~~g~~)(1 ~~mol~~/18.02 ~~g~~)(1000 J/1 kJ)= 5.64 x 10^4 J

❺heating steam= $\Delta H_5 = C_{stm}$*amt*ΔT = (1.841 J/~~g°C~~)(25 ~~g~~)(115~~°C~~-100~~°C~~) = 6.90 x 10^2 J

Add all steps together to obtain $\Delta H_{overall}$.

$\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$ = 6.80 x 10^2 J + 8.35 x 10^3 J + 1.05 x 10^4 J + 5.64 x 10^4 J + 6.90 x 10^2 J =

ΔH = 76620 J = 76.620 kJ which rounds to 77 kJ

✔✔✔■Calculating ΔH when a Substance is Heated or Cooled (continued)

10. A. 43 grams of steam at 312^{o}C is changed into ice at -53^{o}C.

a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.

b) Calculate the heat change for the overall process.

B. 10 grams of ice at -23^{o}C is changed into steam at 103^{o}C.

a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.

b) Calculate the heat change for the overall process.

✔✔✔■Calculating Heat Changes When a Substance is Heated or Cooled (continued)

10. C. 13 grams of ice at -43^{o}C is changed into steam at 125^{o}C.
   a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.

   b) Calculate the heat change for the overall process.

D. 15 grams of steam at 135^{o}C is changed into ice at -11^{o}C.
   a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.

   b) Calculate the heat change for the overall process.

✔✔✔■*Calculating Heat Changes When a Substance is Heated or Cooled (continued)*

10. E. 25 grams of steam at 115^{o}C is changed into ice at -18^{o}C.

a) Draw a sketch breaking the overall process into parts. Then describe each of the parts.

b) Calculate the heat change for the overall process.

■*Challenge Questions*

A. How much ice at 0^{o}C would you need to add to 400 ml of water at room temperature in order to cool it to exactly 40^{o}F and use up all the ice in doing so?

B. 250 milliliters of water at room temperature and 50 grams of ice at 0^{o}C are mixed in a container which allows no transfer of heat with the surroundings. What will be the temperature of the mixture when all of the ice melts?

C. When sulfur is heated above melting, it is found that the normal S_8 molecules combine to form long chains of S atoms with a general formula of S_x. What would happen to the vapor pressure of melted sulfur as this process occurs? Explain in detail in terms of intermolecular forces.

D. 350 milliliters of water at room temperature and 25 grams of ice at 0^{o}C are mixed in a container which allows no transfer of heat with the surroundings. What will be the temperature of the mixture when all of the ice melts?

E. How much ice would you need to add to 500 ml of water at 100^{o}F in order to cool it to exactly 35^{o}F and use up all the ice in doing so?

F. How much ice would you need to add to 250 ml of water at 90^{o}F in order to cool it to exactly 50^{o}F and use up all the ice in doing so?

Updated by JWC 1/26/97, 12/9/98, 12/14/99, MRA 12/18/00, JAP 12/17/01; Revised by SJB 12/12/02