

Lecture 7 CH131 Summer 1

Friday, May 31, 2019

The will be lab today, Friday, May 31

- Complete: Intermolecular forces
- Phase diagrams

Triple point YouTube video: <http://goo.gl/4K1SR>Supercritical fluid YouTube video: <http://goo.gl/xo2jU>

- Liquid-vapor equilibrium: Vapor pressure and boiling
- Relative boiling points.

Next lecture: Begin ch11: Solutions: Colligative properties summary. Vapor pressure lowering (& boiling point elevation). Freezing point depression. Osmotic pressure.



Lecture 7 CH131 Summer 1 2019

Copyright © 2019 Dan Dill dan@bu.edu

[TP] Which of the following are associated with **intramolecular** forces (forces **within** molecule)?

0% 1. Fog forms on a cold morning

0% 2. Wet clothes are hung out to dry

7% 3. Ice melts -

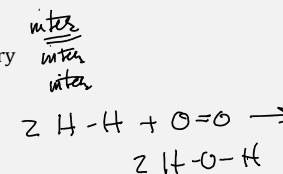
7% 4. 1 and 2

50% 5. 1 and 3

0% 6. 2 and 3

0% 7. All of the above

36% 8. None of the above



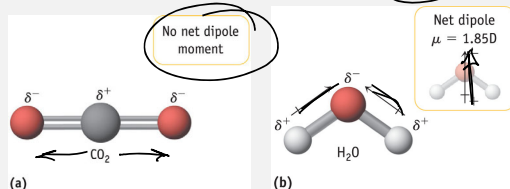
2

Lecture 7 CH131 Summer 1 2019

Copyright © 2019 Dan Dill dan@bu.edu

Molecular polarity

- If bond dipoles **cancel**, molecule is **nonpolar**
- If bond dipoles **do not cancel**, molecule is **polar**

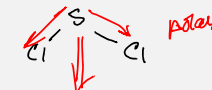
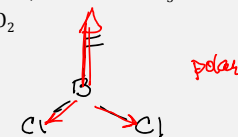


3

Lecture 7 CH131 Summer 1 2019

Copyright © 2019 Dan Dill dan@bu.edu

[TP] Which of the following molecules are **not** polar?

7% 1. BFCl_2 , whose shape is **trigonal-planar**, like that of BF_3 0% 2. SCl_2 , which is a **bent** molecule, like H_2O 0% 3. NH_2Cl , whose shape is **trigonal-pyramidal**, like that of NH_3 57% 4. OCS , which is a **linear** molecule, like CO_2 0% 5. All of the above are **nonpolar**36% 6. All of the above are **polar**

4

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[Quiz] Which of the following bonds is the **most polar**? CO, CTe, SnO or SnTe?

0% 1. CO
 100% 2. SnO
 0% 3. CTe
 0% 4. SnTe

BOSTON UNIVERSITY 5

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Dipole can be attractive or repulsive

BOSTON UNIVERSITY 6

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Dispersion forces due to induced dipoles

(a) $t=0$

(b) $t=1$

(c)

BOSTON UNIVERSITY 7

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Dispersion always attractive

BOSTON UNIVERSITY 8

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Hydrogen bonding is **directional**

<chem>N-H...N-</chem>	<chem>O-H...N-</chem>	<chem>F-H...N-</chem>
<chem>N-H...O-</chem>	<chem>O-H...O-</chem>	<chem>F-H...O-</chem>
<chem>N-H...F-</chem>	<chem>O-H...F-</chem>	<chem>F-H...F-</chem>

BOSTON UNIVERSITY

9

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Hydrogen bonds are **long**

<chem>N-H...N-</chem>	<chem>O-H...N-</chem>	<chem>F-H...N-</chem>
<chem>N-H...O-</chem>	<chem>O-H...O-</chem>	<chem>F-H...O-</chem>
<chem>N-H...F-</chem>	<chem>O-H...F-</chem>	<chem>F-H...F-</chem>

BOSTON UNIVERSITY

10

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Phase diagrams

Lines of p versus T for which different phases are present **at the same time**.

That is, values of p and T for which different phases are **in equilibrium**.

BOSTON UNIVERSITY

11

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Phase diagrams

BOSTON UNIVERSITY

12

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

How about on blue line at 45 °C, point c?

Pressure (kPa)

Temperature (°C)

Normal freezing point

Normal boiling point

101.325 kPa

0.6117 kPa

0 0.01 100

Solid Liquid Vapour

Boston University

13

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

What about the intersection marked "A"?

Pressure (kPa)

Temperature (°C)

Normal freezing point

Normal boiling point

101.325 kPa

0.6117 kPa

0 0.01 100

Solid Liquid Vapour

Boston University

14

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Triple point

Liquid tert-butyl alcohol, $C(CH_3)_3OH$, can boil and freeze at the same time...
<http://goo.gl/4K1SR>

Pressure (kPa)

Temperature (°C)

Normal freezing point

Normal boiling point

101.325 kPa

0.6117 kPa

0 0.01 100

Solid Liquid Vapour

Boston University

15

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Supercritical fluid

Supercritical transition of liquid Cl_2 ... <http://goo.gl/xo2jU>

Pressure (kPa)

Temperature (°C)

Normal freezing point

Normal boiling point

101.325 kPa

7390 kPa

518 kPa

0.6117 kPa

-100 -60 -56.6 0 +20 +60

Solid Liquid Gas

Boston University

16

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Changes of phase

CO₂ gas at 1 atm, 0 °C
 is heated to 1 atm, 60 °C;
 then compressed to 75 atm, 60 °C;
 then cooled to 75 atm, 0 °C;
 then expanded to 73 atm, 0 °C.
 At this point, the CO₂ will be a ...

75 atm
73 atm
1 atm

Pressure (kPa)
 $P_c = 7390$ kPa
 Critical point
 "Supercritical fluid"
 Solid
 Liquid
 Gas
 518 kPa
 Triple point
 -56.6 °C
 $T_c = +31$ °C
 Temperature (°C)

BOSTON UNIVERSITY

17

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[TP] CO₂ gas at 1 atm, 0 °C
 is heated to 1 atm, 60 °C;
 then compressed to 75 atm, 60 °C;
 then cooled to 75 atm, 0 °C;
 then expanded to 73 atm, 0 °C.
 At this point, the CO₂ will be a ...

0% 1. gas
 15% 2. supercritical fluid
 85% 3. liquid
 0% 4. solid

Pressure (kPa)
 $P_c = 7390$ kPa
 Critical point
 "Supercritical fluid"
 Solid
 Liquid
 Gas
 518 kPa
 Triple point
 -56.6 °C
 $T_c = +31$ °C
 Temperature (°C)

BOSTON UNIVERSITY

18

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[Quiz] CO₂ at 1 atm, 0 °C
 is heated to 1 atm, 60 °C;
 then compressed to 75 atm, 60 °C;
 then cooled to 75 atm, 0 °C;
 then expanded to 73 atm, 0 °C.
 At this point, the CO₂ will have
 undergone a phase transition ...

27% 1. once
 0% 2. twice
 0% 3. three times
 73% 4. None of the above

dense gas
diffuse liquid

Pressure (kPa)
 $P_c = 7390$ kPa
 Critical point
 "Supercritical fluid"
 Solid
 Liquid
 Gas
 518 kPa
 Triple point
 -56.6 °C
 $T_c = +31$ °C
 Temperature (°C)

BOSTON UNIVERSITY

19

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Phase diagrams are specific to each substance

Water

101.325 kPa
 Normal freezing point
 Normal boiling point
 Solid
 Liquid
 Vapour
 0.6117 kPa
 Triple point
 0.01
 100
 Temperature (°C)

CO₂ $l = 1$
 $g = p$

Pressure (kPa)
 $P_c = 7390$ kPa
 Critical point
 "Supercritical fluid"
 Solid
 Liquid
 Gas
 518 kPa
 Triple point
 -56.6 °C
 $T_c = +31$ °C
 Temperature (°C)

BOSTON UNIVERSITY

20

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Liquid-vapor equilibrium

Hand-drawn sketches include a graph of pressure vs. temperature with a boiling point of 80°C, and molecular models of liquid and vapor states. The liquid state is labeled 'liquid' and the vapor state is labeled 'Vapour'.

BOSTON UNIVERSITY

21

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[TP] A bubble in a pot of boiling water contains...

- 0% 1. Only $O_2(g)$ and $H_2(g)$
- 60% 2. Only $H_2O(g)$
- 0% 3. Only air
- 20% 4. $H_2O(g)$ and air
- 13% 5. All of the above equally
- 7% 6. None of the above

BOSTON UNIVERSITY

22

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Vapor pressure and boiling point

The normal boiling point is the temperature at which bubbles form at 1 atm.
What do you predict for relative boiling points of these substances?

Substance	Vapor pressure at 25 °C, kPa	Normal (1 atm) boiling point °C
Acetone, $CH_3C(O)CH_3$	30.8	
Diethyl ether, $(CH_3CH_2)_2O$	71.7	
Ethanol, CH_3CH_2OH	7.87	
Water, H_2O	3.17	100

Hand-drawn graph shows vapor pressure vs. temperature. The boiling point of water is marked at 100°C and 101.3 kPa. The vapor pressure of acetone at 25°C is marked as 30.8 kPa.

BOSTON UNIVERSITY

23

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[TP] The order of normal boiling points is ...

- 80% 1. diethyl ether < acetone < ethanol
- 20% 2. ethanol < acetone < diethyl ether
- 0% 3. acetone < diethyl ether < ethanol
- 0% 4. diethyl ether < ethanol < acetone
- 0% 5. something else

Substance	Vapor pressure at 25 °C, kPa	Normal (1 atm) boiling point °C
Acetone, $CH_3C(O)CH_3$	30.8	
Diethyl ether, $(CH_3CH_2)_2O$	71.7	
Ethanol, CH_3CH_2OH	7.87	
Water, H_2O	3.17	100

BOSTON UNIVERSITY

24

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Vapor pressure and boiling point

The normal boiling point is the temperature at which **bubbles** form at **1 atm**.
What do you predict for **relative boiling points** of these substances?

Substance	Vapor pressure at 25 °C, kPa	Normal (1 atm) boiling point °C
Acetone, $\text{CH}_3\text{C}(\text{O})\text{CH}_3$	3: 30.8	3: 56
Diethyl ether, $(\text{CH}_3\text{CH}_2)_2\text{O}$	4: 71.7	4: 35
Ethanol, $\text{CH}_3\text{CH}_2\text{OH}$	2: 7.87	2: 78
Water, H_2O	1: 3.17	1: 100

BOSTON UNIVERSITY 25

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Vapor pressure and boiling point

The normal boiling point is the temperature at which **bubbles** form at **1 atm**.
Sketch the four $l - g$ phase diagrams.

Substance	Vapor pressure at 25 °C, kPa	Normal (1 atm) boiling point °C
Acetone, $\text{CH}_3\text{C}(\text{O})\text{CH}_3$	3: 30.8	3: 56
Diethyl ether, $(\text{CH}_3\text{CH}_2)_2\text{O}$	4: 71.7	4: 35
Ethanol, $\text{CH}_3\text{CH}_2\text{OH}$	2: 7.87	2: 78
Water, H_2O	1: 3.17	1: 100

BOSTON UNIVERSITY 26

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Challenge: Normal boiling point, T_b

The normal boiling point is the temperature at which **bubbles** form at **1 atm**.

Substance	T_b
Water (H_2O)	100 °C
Ammonia (NH_3)	-33.3 °C
Hydrogen chloride (HCl)	-84.8 °C
Methane (CH_4)	-161.5 °C
Nitrogen (N_2)	-195.8 °C

What do you predict for **relative vapor pressures** of these substances at **-200 °C**?

BOSTON UNIVERSITY 27

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

[Quiz] The substance with the **lowest vapor pressure** substances at **-200 °C** is ...

Substance	T_b
Water (H_2O)	100 °C
Ammonia (NH_3)	-33.3 °C
Hydrogen chloride (HCl)	-84.8 °C
Methane (CH_4)	-161.5 °C
Nitrogen (N_2)	-195.8 °C

0% 1. CH_4
100% 2. NH_3
0% 3. HCl
0% 4. N_2

BOSTON UNIVERSITY 28

Lecture 7 CH131 Summer 1 2019 Copyright © 2019 Dan Dill dan@bu.edu

Challenge: Normal boiling point, T_b

The normal boiling point is the temperature at which **bubbles** form at **1 atm**.

Sketch the four $l-g$ phase diagrams.

Substance	T_b
Water (H_2O)	100 °C
Ammonia (NH_3)	-33.3 °C
Hydrogen chloride (HCl)	-84.8 °C
Methane (CH_4)	-161.5 °C
Nitrogen (N_2)	-195.8 °C

BOSTON UNIVERSITY

29