

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

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

13% 1. Fog forms on a cold morning  
 13% 2. Wet clothes are hung out to dry  
 13% 3. Ice melts  
 13% 4. 1 and 2  
 13% 5. 1 and 3  
 13% 6. 2 and 3  
 13% 7. All of the above  
 13% 8. None of the above

BOSTON UNIVERSITY

Response Counter

10 1

Lecture 14 CH101 A2 (MWF 11:15 am)  
 Tuesday, October 10, 2017

For today ...

- Review: Vapor pressure and “boiling”
- Intermolecular forces
- Hydrogen bonding
- Polarity

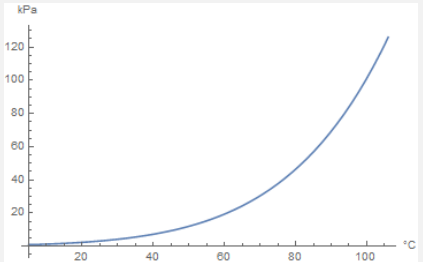
Next lecture: Dipole-dipole interaction versus temporary dipole attraction (dispersion); Relative boiling points

BOSTON UNIVERSITY

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Vapor pressure and boiling

Vapor pressure rises with temperature.



The graph shows vapor pressure in kPa on the y-axis (0 to 120) and temperature in °C on the x-axis (0 to 100). The curve starts near 0 at 0°C and rises exponentially, reaching approximately 101.325 kPa at 100°C.

BOSTON UNIVERSITY

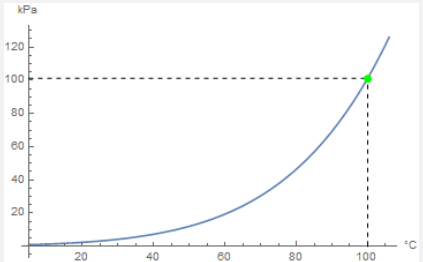
3

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Vapor pressure and boiling

Bubbles appear when vapor pressure = applied pressure

“Normal” boiling point is when vapor pressure is exactly 1 atm = 101.325 kPa



The graph shows vapor pressure in kPa on the y-axis (0 to 120) and temperature in °C on the x-axis (0 to 100). A blue curve represents the vapor pressure. A green dot is placed on the curve at the point where the temperature is 100°C and the vapor pressure is 101.325 kPa. Dashed lines connect this point to the axes.

BOSTON UNIVERSITY

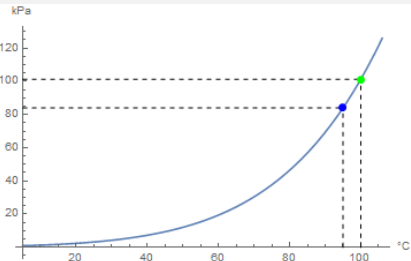
4

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

## Vapor pressure and boiling

Bubbles appear when vapor pressure = applied pressure

A **vacuum pump** allows boiling at **lower temperature**.



The graph shows vapor pressure in kPa on the y-axis (0 to 120) and temperature in °C on the x-axis (0 to 100). A blue curve represents the vapor pressure. A green dot is at (100, 101) and a blue dot is at (95, 80). Dashed lines connect these points to the axes.

BOSTON UNIVERSITY

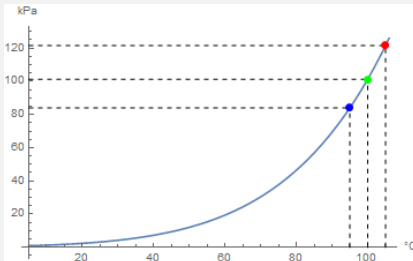
5

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

## Vapor pressure and boiling

Bubbles appear when vapor pressure = applied pressure

A **pressure cooker** delays boiling to **higher temperature**.



The graph shows vapor pressure in kPa on the y-axis (0 to 120) and temperature in °C on the x-axis (0 to 100). A blue curve represents the vapor pressure. A green dot is at (100, 101) and a red dot is at (105, 120). Dashed lines connect these points to the axes.

BOSTON UNIVERSITY

6

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

## Intramolecular and intermolecular forces

**Inter**molecular forces are forces of attraction **between molecules**

Chemical changes are related to breaking and formation of covalent **bonds** due to **intramolecular** forces **within molecules**.

**Physical changes** are governed by **inter**molecular forces

BOSTON UNIVERSITY

7

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

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

13% 1. Fog forms on a cold morning

13% 2. Wet clothes are hung out to dry

13% 3. Ice melts

13% 4. 1 and 2

13% 5. 1 and 3

13% 6. 2 and 3

13% 7. All of the above

13% 8. None of the above

BOSTON UNIVERSITY

Response Counter 10 8


Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Intermolecular forces: stickiness!

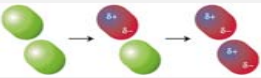
A molecules attract one another, because of the attraction of opposite electrical charges.

Most specific and **strongest** is "hydrogen bonding":  $X-H \cdots Y$

More common and **intermediate strength** is "dipole-dipole attraction":



Always present and **weakest** is "temporary dipole attraction" ("dispersion interaction"):

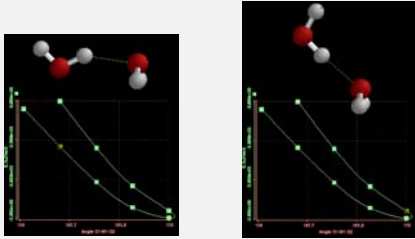


BOSTON UNIVERSITY 9

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Hydrogen bond angle is 180°

$N-H \cdots N$	$O-H \cdots N$	$F-H \cdots N$
$N-H \cdots O$	$O-H \cdots O$	$F-H \cdots O$
$N-H \cdots F$	$O-H \cdots F$	$F-H \cdots F$

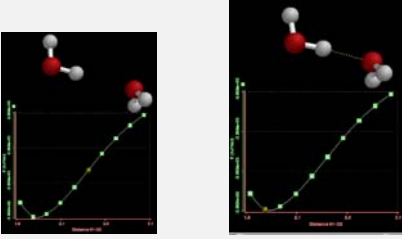


BOSTON UNIVERSITY 14

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Hydrogen bonds are longer than typical bonds

$N-H \cdots N$	$O-H \cdots N$	$F-H \cdots N$
$N-H \cdots O$	$O-H \cdots O$	$F-H \cdots O$
$N-H \cdots F$	$O-H \cdots F$	$F-H \cdots F$



BOSTON UNIVERSITY 15

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Which of the following cannot form H bonds?

- Ammonia,  $NH_3$
- Methanol,  $CH_3OH$
- Ethanol,  $CH_3CH_2OH$
- Dimethyl ether,  $CH_3OCH_3$

BOSTON UNIVERSITY 16

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017

Copyright © 2016 Dan Dill dan@bu.edu

[Quiz] Which of the following **cannot** form hydrogen bonds with themselves?

- 0% 1. Ammonia,  $\text{NH}_3$
- 0% 2. Methanol,  $\text{CH}_3\text{OH}$
- 0% 3. Ethanol,  $\text{CH}_3\text{CH}_2\text{OH}$
- 0% 4. Dimethyl ether,  $\text{CH}_3\text{OCH}_3$
- 0% 5. 1 and 3
- 0% 6. 1 and 4
- 0% 7. 2 and 4
- 0% 8. All of the above can form hydrogen bonds with themselves



17

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017

Copyright © 2016 Dan Dill dan@bu.edu

## Dipole-dipole attraction

Molecules must be "polar"



What makes a molecule polar is **unequal sharing of electron clouds**.

Sharing tendency is proportional to **electronegativity difference**.

The greater the **difference of electronegativities**,  
the **more unequal the sharing**,  
the **more polar** the shared electron cloud.



18

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017

Copyright © 2016 Dan Dill dan@bu.edu

## Electronegativity $\chi$ : Relative pull

1	2											13	14	15	16	17
Li 1.0	Be 1.6											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.3											Al 1.6	Si 1.9	P 2.2	S 2.6	Cl 3.2
K 0.8	Ca 1.0	Sc 1.4	Ti 1.5	V 1.6	Cr 1.7	Mn 1.5	Fe 1.8	Co 1.9	Ni 1.9	Cu 1.9	Zn 1.6	Ga 1.8	Ge 2.0	As 2.2	Se 2.6	Br 3.0
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.3	Nb 1.6	Mo 2.2	Tc 1.9	Ru 2.2	Rh 2.3	Pd 2.2	Ag 1.9	Cd 1.7	In 1.8	Sn 2.0	Sb 1.9	Te 2.1	I 2.7
Cs 0.8	Ba 0.9	La 1.1	Hf 1.3	Ta 1.5	W 2.4	Re 1.9	Os 2.2	Ir 2.2	Pt 2.3	Au 2.5	Hg 2.0	Tl 1.6	Pb 2.3	Bi 2.0	Po 2.0	At 2.2

<1.0
1.5-1.9
2.5-2.9  
1.0-1.4
2.0-2.4
3.0-4.0

FIGURE 6.11 Estimates of the electronegativities of the elements.

The **larger  $\chi$**  the more **piggish** the atom

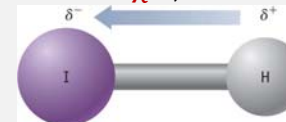


19

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017

Copyright © 2016 Dan Dill dan@bu.edu

The **more different the  $\chi$ 's**, the **more polar the bond**



- If two bonded atoms are **different**, the one with **larger  $\chi$**  gets **more** of the **shared electron cloud**
- Atom with **larger  $\chi$**  has net **negative** charge; atom with **smaller  $\chi$**  has net **positive** charge
- The larger the difference in  $\chi$ , the greater the charge separation (unequal sharing of electron cloud)
- Result is a **polar bonds**



20

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Molecular polarity

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

(a)

(b)

Let's illustrate, for  $\text{BF}_3$  and  $\text{BH}_2\text{F}$

21

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Consider polarity of the following

- $\text{BFCl}_2$ , whose shape is **trigonal-planar**, like that of  $\text{BF}_3$
- $\text{SCl}_2$ , which is a **bent** molecule, like  $\text{H}_2\text{O}$
- $\text{NH}_2\text{Cl}$ , whose shape is **trigonal-pyramidal**, like that of  $\text{NH}_3$
- $\text{OCS}$ , which is a **linear** molecule, like  $\text{CO}_2$

23

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

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

- 17%  $\text{BFCl}_2$ , whose shape is **trigonal-planar**, like that of  $\text{BF}_3$
- 17%  $\text{SCl}_2$ , which is a **bent** molecule, like  $\text{H}_2\text{O}$
- 17%  $\text{NH}_2\text{Cl}$ , whose shape is **trigonal-pyramidal**, like that of  $\text{NH}_3$
- 17%  $\text{OCS}$ , which is a **linear** molecule, like  $\text{CO}_2$
- 17% All of the above are **nonpolar**
- 17% All of the above are **polar**

Response Counter 10 24

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

[Quiz] Which of the following statements is true about carbon dioxide,  $\text{O}=\text{C}=\text{O}$ ?

- 25%  $\text{CO}_2$  contains polar bonds and is a polar molecule
- 25%  $\text{CO}_2$  contains polar bonds, but is not a polar molecule
- 25%  $\text{CO}_2$  does not contain polar bonds and is not a polar molecule
- 25%  $\text{CO}_2$  does not contain polar bonds but is a polar molecule

Response Counter 10 25

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

Dipole-dipole versus dispersion

BOSTON UNIVERSITY

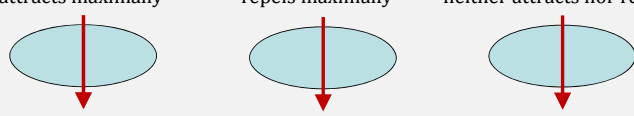
26

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Permanent dipoles

Sketch a second molecule arranged so that it ...

attracts maximally      repels maximally      neither attracts nor repels

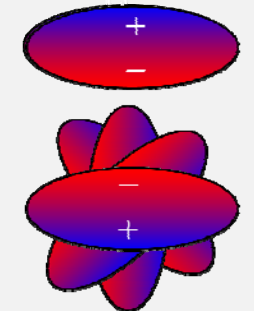


BOSTON UNIVERSITY

27

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Dipole can be attractive or repulsive

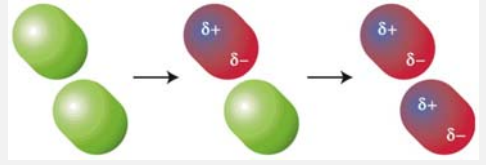


BOSTON UNIVERSITY

28

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Dispersion forces are due to induced dipoles



BOSTON UNIVERSITY

29

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Induced dipoles

Sketch the induced dipole in each case:

BOSTON UNIVERSITY 30

Lecture 14 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

### Dispersion always attractive

BOSTON UNIVERSITY 31