

Lecture 13 CH101 A2 (MWF 11:15 am) Fall 2017 Copyright © 2016 Dan Dill dan@bu.edu

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

Substance	Vapor pressure at 25 °C, kPa	Normal (1 atm) boiling point °C
Acetone, CH ₃ C(O)CH ₃	30.8	
Diethyl ether, (CH ₃ CH ₂) ₂ O	71.7	
Ethanol, CH ₃ CH ₂ OH	7.87	
Water, H ₂ O	3.17	100

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

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Response Counter

10 1

Lecture 13 CH101 A1 (MWF 9:05 am)
 Friday, October 6, 2017

For today ...

- Vapor pressure and boiling


Next lecture: Intermolecular forces; hydrogen bonding; dipole-dipole interaction (polarity); temporary dipole attraction (dispersion); relative boiling points

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[TP] From e6.4 (p 163): A bubble in a pot of boiling water contains...

17% 1. Only O₂(g) and N₂(g)
 17% 2. Only H₂O(g)
 17% 3. Only air
 17% 4. H₂O(g) and air
 17% 5. All of the above equally
 17% 6. None of the above



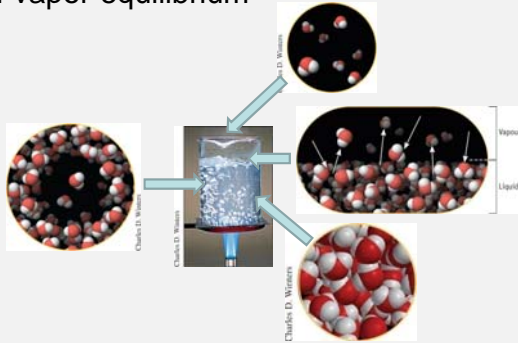
Charles D. Wilmer

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Liquid-vapor equilibrium



Charles D. Wilmer

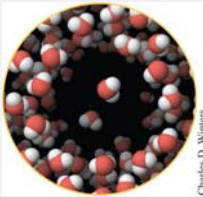
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Boiling: Fig 6.7, p 164

Boiling means "bubbles"
Bubbles are pure vapor of the liquid



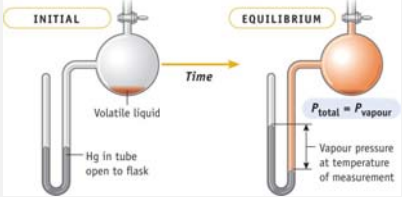
Substance	Equilibrium Vapour Pressure (kPa)
Water, H ₂ O(l)	3.17
Ethanol, C ₂ H ₅ OH(l)	7.87
Hexane, C ₆ H ₁₄ (l)	20.2
Bromine, Br ₂ (l)	28.7
Acetone, CH ₃ COCH ₃ (l)	30.8
Carbon disulfide, CS ₂ (l)	48.2
Diethyl ether, C ₂ H ₅ O ₂ H ₆ (l)	71.7

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Equilibrium vapor pressure



INITIAL EQUILIBRIUM

Time

Volatile liquid

Hg in tube open to flask

$P_{total} = P_{vapour}$

Vapour pressure at temperature of measurement

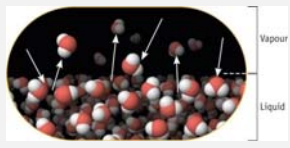
1 Pa = force/area = 1 kg m/s² / m² = 1 kg m⁻¹ s⁻²
1 bar = 100 kPa (exactly)
1 atm = 101.325 kPa (exactly)

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Equilibrium vapor pressure



INITIAL EQUILIBRIUM

Time

Volatile liquid

Hg in tube open to flask

$P_{total} = P_{vapour}$

Vapour pressure at temperature of measurement

Vapour

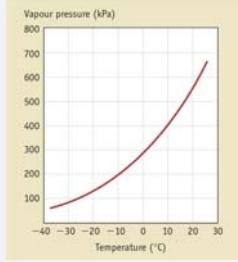
Liquid

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Equilibrium vapor pressure



INITIAL EQUILIBRIUM

Time

Volatile liquid

Hg in tube open to flask

$P_{total} = P_{vapour}$

Vapour pressure at temperature of measurement

Vapour pressure (kPa)

Temperature (°C)

Low temperature
→ Few particles in vapor
→ Low equilibrium vapor pressure

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Equilibrium vapor pressure

INITIAL → EQUILIBRIUM

Volatile liquid

Hg in tube open to flask

Time

$P_{\text{total}} = P_{\text{vapour}}$

Vapour pressure at temperature of measurement

Vapour pressure (kPa)

Temperature (°C)

Higher temperature
 → More particles in vapor
 → Higher equilibrium vapor pressure

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Equilibrium vapor pressure

INITIAL → EQUILIBRIUM

Volatile liquid

Hg in tube open to flask

Time

$P_{\text{total}} = P_{\text{vapour}}$

Vapour pressure at temperature of measurement

Vapour pressure (kPa)

Temperature (°C)

Normal boiling temperature
 → Maximum particles in vapor
 → 1 atm equilibrium vapor pressure

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Vapor pressure and boiling point

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

Can we make bubbles (and so "boil") at a lower temperature?

Let's see ...

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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**

kPa

Temperature (°C)

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Vapor pressure and boiling

Bubbles appear when vapor pressure = applied pressure

A vacuum pump allows boiling at lower temperature.

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Vapor pressure and boiling

Bubbles appear when vapor pressure = applied pressure

A pressure cooker delays boiling to higher temperature.

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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 ₃ C(O)CH ₃	30.8	
Diethyl ether, (CH ₃ CH ₂) ₂ O	71.7	
Ethanol, CH ₃ CH ₂ OH	7.87	
Water, H ₂ O	3.17	100

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

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20% 2. ethanol < acetone < diethyl ether

20% 3. acetone < diethyl ether < ethanol

20% 4. ethanol < diethyl ether < acetone

20% 5. something else

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Response Counter 10 20

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 ₃ C(O)CH ₃	3:30.8	3:56
Diethyl ether, (CH ₃ CH ₂) ₂ O	4:71.7	4:35
Ethanol, CH ₃ CH ₂ OH	2:7.87	2:78
Water, H ₂ O	1:3.17	1:100

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Relative normal boiling point, T_b

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

Substance	T_b
Water (H ₂ O)	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**?

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

Substance	T_b
Water (H ₂ O)	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

25% 1. CH₄
25% 2. NH₃
25% 3. HCl
25% 4. N₂

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Response Counter

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Enthalpy change of vaporization, $\Delta_{\text{vap}}H$

Substance	$\Delta_{\text{vap}}H$ (kJ mol ⁻¹)
Water (H ₂ O)	40.7
Ammonia (NH ₃)	23.3
Hydrogen chloride (HCl)	16.2
Methane (CH ₄)	8.2
Nitrogen (N ₂)	5.6

Charles D. Wilcox

H₂O(l) ⇌ H₂O(g), $\Delta_{\text{vap}}H = 40.7$ kJ/mol at **100 °C**
 NH₃(l) ⇌ NH₃(g), $\Delta_{\text{vap}}H = 23.3$ kJ/mol at **-78 °C**
 N₂(l) ⇌ N₂(g), $\Delta_{\text{vap}}H = 5.6$ kJ/mol at **-196 °C**
 etc.

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[TP] Which of the following is correct about water?

- 20% 1. The low enthalpy of vaporization results in a low vapor pressure at room temperature
- 20% 2. The high enthalpy of vaporization results in a low vapor pressure at room temperature
- 20% 3. The low enthalpy of vaporization results in a high vapor pressure at room temperature
- 20% 4. The high enthalpy of vaporization results in a high vapor pressure at room temperature
- 20% 5. There is no simple relationship between vapor pressure and enthalpy of vaporization

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