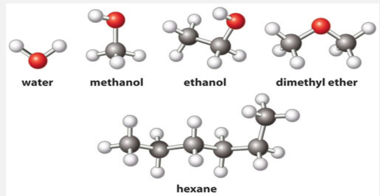
[TP] Which of the following cannot form H-bonds between themselves?

0%	1.	Ammonia, NH_3
0%	2.	Methanol, CH_3OH
0%	3.	Ethanol, CH_3CH_2OH
0%	4.	Dimethyl ether, CH_3OCH_3
0%	5.	1 and 3
0%	6.	1 and 4
0%	7.	2 and 4
100%	8.	All of the above can form hydrogen bonds with themselves
0%	9.	Not sure



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Lecture 8 CH131 Summer 1 2021

Tuesday, June 8, 2021

- H-bonding IMF dominate London IMF
- Summary: Three kinds of IMF: London, H-bond, dipole-dipole
- Practice: Boiling points and enthalpy of vaporization
- Vapor pressure: Liquid-vapor equilibrium
- Vapor pressure and boiling point
- Phase diagrams

Next: Complete: Phase diagrams; Ch11: Solutions

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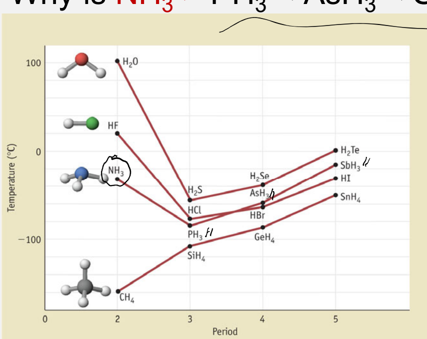
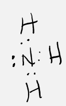
Why is $NH_3 > PH_3 < AsH_3 < SbH_3$?





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Hydrogen bonding

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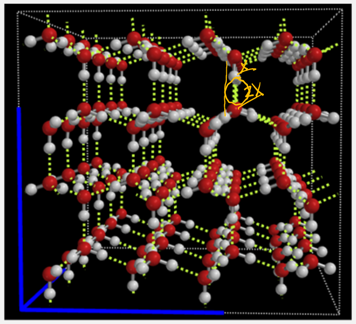
Ice



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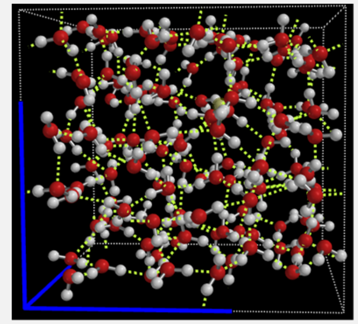
Water



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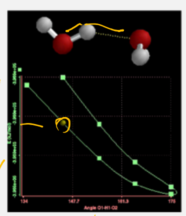
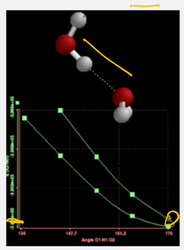
O–H···O angle is 180°

N—H - - - :N—	O—H - - - :N—	F—H - - - :N—
N—H - - - :O—	O—H - - - :O—	F—H - - - :O—
N—H - - - :F—	O—H - - - :F—	F—H - - - :F—





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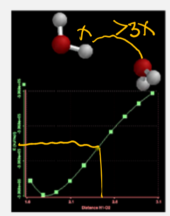
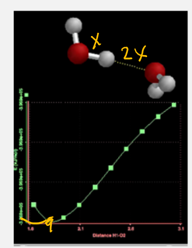
H···O bond is longer than O–H bond

N—H - - - :N—	O—H - - - :N—	F—H - - - :N—
N—H - - - :O—	O—H - - - :O—	F—H - - - :O—
N—H - - - :F—	O—H - - - :F—	F—H - - - :F—





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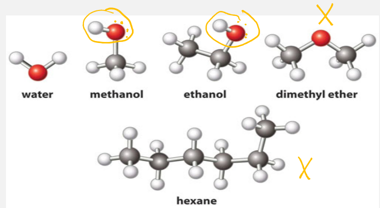
[TP] Which of the following cannot form H-bonds between themselves?

- 0% 1. Ammonia, NH_3
- 0% 2. Methanol, CH_3OH
- 0% 3. Ethanol, CH_3CH_2OH
- 92% 4. Dimethyl ether, CH_3OCH_3
- 0% 5. 1 and 3
- 8% 6. 1 and 4
- 0% 7. 2 and 4
- 0% 8. All of the above can form hydrogen bonds with themselves
- 0% 9. Not sure



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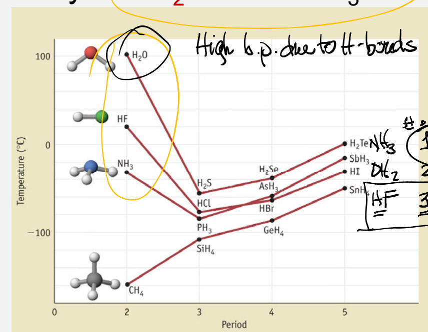
Why is OH_2 > FH > NH_3?



High b.p. due to H-bonds

highest London

lowest London

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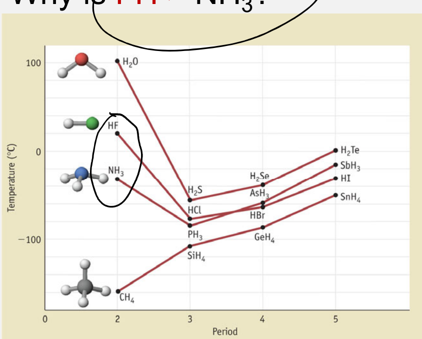
Why is FH > NH_3?



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[TP] Why does FH boil at a higher temperature than NH_3?

- 0% 1. FH is more polar ✗ Not relevant.
- 92% 2. The electron cloud of FH is larger
- 0% 3. FH forms more H bonds ✗
- 0% 4. F is more electronegative than N ✗ not relevant
- 0% 5. 1 and 2
- 0% 6. 1, 2, and 3
- 8% 7. 1, 2, 3, and 4
- 0% 8. Not sure

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Intermolecular forces (IMF) summary

There are three kinds of Coulomb interactions between neutral particles, in order of decreasing importance:

If hydrogen bonds are possible, they are the dominant IMF.

Otherwise, London forces are the dominant IMF.

Dipole-dipole interaction is important only when molecules of similar London IMF have very different polarities.

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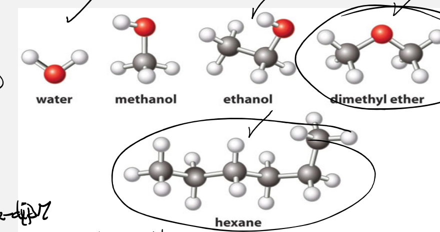
[TP] Identify the compound with the smallest energy of vaporization (kJ/mol).

- 0% 1. water
- 0% 2. ethanol
- 100% 3. dimethyl ether
- 0% 4. Hexane
- 0% 5. Not sure



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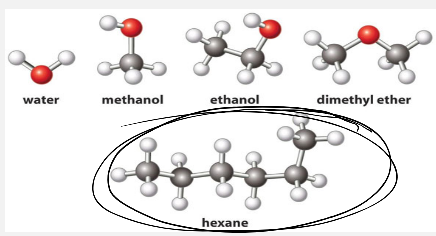
[TP] Identify the compound with the largest energy of vaporization (kJ/mol).

- 85% 1. water
- 15% 2. ethanol
- 0% 3. dimethyl ether
- 0% 4. Hexane
- 0% 5. Not sure



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When London IMF is very large, it dominates

C_6H_{14}: 69°C

C_7H_{16}: 98°C

H_2O: 100°C

C_8H_{18}: 126°C

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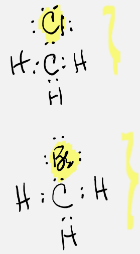
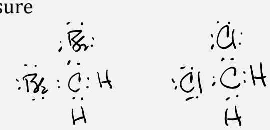
[TP] The correct order of boiling point of CH_3Br, CH_2Br_2, CH_3Cl, and CH_2Cl_2 (lowest to highest) is …

0%	1.	$CH_2Br_2 < CH_2Cl_2 < CH_3Br < CH_3Cl$
0%	2.	$CH_2Cl_2 < CH_2Br_2 < CH_3Cl < CH_3Br$
92%	3.	$CH_3Cl < CH_3Br < CH_2Cl_2 < CH_2Br_2$
0%	4.	$CH_3Br < CH_3Cl < CH_2Br_2 < CH_2Cl_2$
0%	5.	$CH_3Cl < CH_3Br < CH_2Br_2 < CH_2Cl_2$
0%	6.	some other order
8%	7.	Not sure





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Review: Units of pressure

$1\ \mathrm{Pa} = \frac{\text{force}}{\text{area}}$

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Review: Units of pressure

$1\ \mathrm{Pa} = \frac{\text{force}}{\text{area}} = 1\,\frac{\mathrm{kg\ m/s^2}}{\mathrm{m^2}}$

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Review: Units of pressure

$1\ \mathrm{Pa} = \frac{\text{force}}{\text{area}} = 1\,\frac{\mathrm{kg\ m/s^2}}{\mathrm{m^2}} = 1\,\frac{\mathrm{kg\ m^2/s^2}}{\mathrm{m^3}}$

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Review: Units of pressure

$1\ \text{Pa} = \frac{\text{force}}{\text{area}} = 1\ \frac{\text{kg m/s}^2}{\text{m}^2} = 1\ \frac{\text{kg m}^2/\text{s}^2}{\text{m}^3} = 1\ \frac{\text{J}}{\text{m}^3}$

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Review: Units of pressure

$1\ \text{Pa} = \frac{\text{force}}{\text{area}} = 1\ \frac{\text{kg m/s}^2}{\text{m}^2} = 1\ \frac{\text{kg m}^2/\text{s}^2}{\text{m}^3} = 1\ \frac{\text{J}}{\text{m}^3}$

1 bar = 100 kPa (exactly)

1 atm = 101.325 kPa (exactly) = 760 Torr (exactly)

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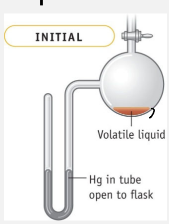
Equilibrium vapor pressure



What is going on at the surface at this point?

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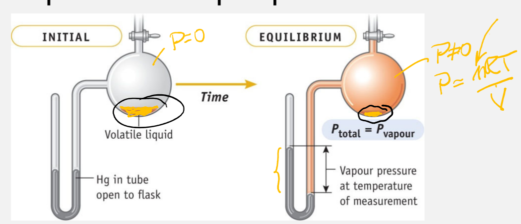
Equilibrium vapor pressure



What is going on at the surface now?

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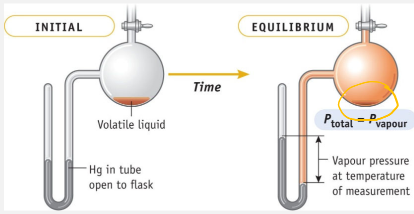
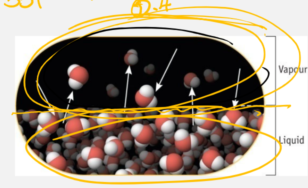
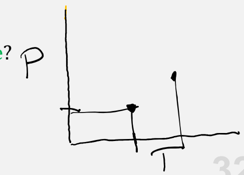
Equilibrium vapor pressure





How must pressure must change with temperature?



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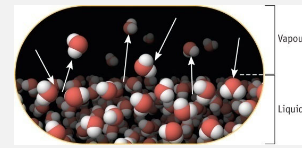
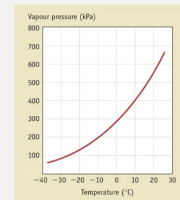
Equilibrium vapor pressure

Vapor pressure must rise with temperature.

Why is this so?





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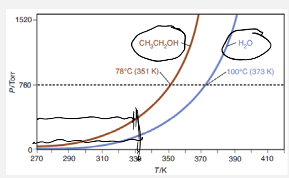
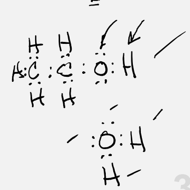
Evaporation

Vapor pressure rises with temperature.

Why is a vapor pressure of ethanol greater?





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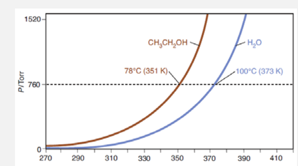
[TP] At 60°C, the vapor pressure of ethanol is greater than that of water. This is because …

0%	1.	water has smaller IMF than ethanol
100%	2.	water has greater IMF than ethanol
0%	3.	water has smaller London IMF
0%	4.	water has greater London IMF
0%	5.	water is more polar
0%	6.	water is less polar
0%	7.	Not sure



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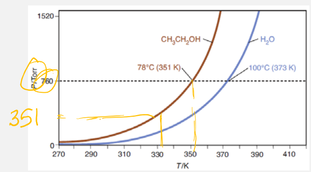
Evaporation

Vapor pressure rises with temperature.

$T = 60.0°C, P_{vapor} = 351$ Torr

$T_{bp} = 78.3°C, P_{vapor} = 760$ Torr



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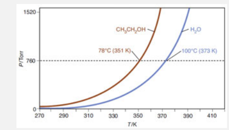
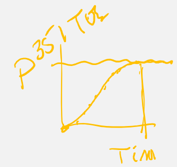
Evaporation

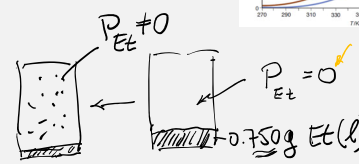
Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?

We know that at 60.0°C, $P_{vapor} = 351$ Torr

How to proceed?







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Evaporation

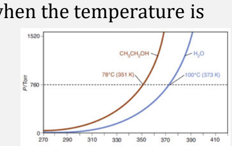
Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?

At 60.0°C, $P_{vapor} = 351$ Torr

$n_{available} = ?$, calculate from molar mass

$n_{vapor} = ?$, calculate from ideal gas law using actual pressure, $P_{vapor} = n_{vapor}RT/V$

If $n_{vapor} < n_{available}$



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Evaporation

Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?

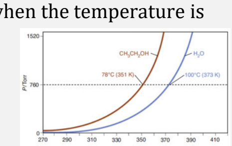
At 60.0°C, $P_{vapor} = 351$ Torr

$n_{available} = ?$, calculate from molar mass

$n_{vapor} = ?$, calculate from ideal gas law, using actual pressure, $P_{vapor} = n_{vapor}RT/V$

If $n_{vapor} < n_{available}$, liquid will remain.

If $n_{vapor} > n_{available}$, liquid will have completely evaporated.



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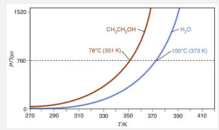
Evaporation

Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?



At 60.0°C, $P_{\text{vapor}} = 351$ Torr

$n_{\text{available}} = 0.0163$ mol

$n_{\text{vapor}} = 0.00675$ mol

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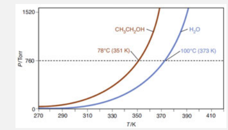
Evaporation

Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?



At 60.0°C, $P_{\text{vapor}} = 351$ Torr

$n_{\text{available}} = 0.0163$ mol

$n_{\text{vapor}} = 0.00675$ mol

Since $n_{\text{vapor}} = 0.00675$ mol $< n_{\text{available}} = 0.0163$ mol, liquid will remain.

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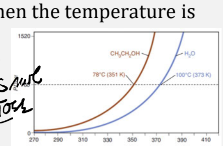
Evaporation

Problem 15-21: A 0.750-gram sample of ethanol (CH_3CH_2OH) is placed in a sealed 400-mL container. Is there any liquid present when the temperature is held at 60°C?



At 60.0°C, $P_{\text{vapor}} = 351$ Torr

$n_{\text{available}} = 0.0163$ mol

$n_{\text{vapor}} = 0.00675$ mol

$n_{\text{liquid}} = n_{\text{available}} - n_{\text{vapor}}$

$= 0.0163 \text{ mol} - 0.00675 \text{ mol}$

$= 0.0096$ mol

V=0.400 L, n=0.00675 mol, P = 351 Torr

See slide 31

If $n_{avail} = 0.00400$

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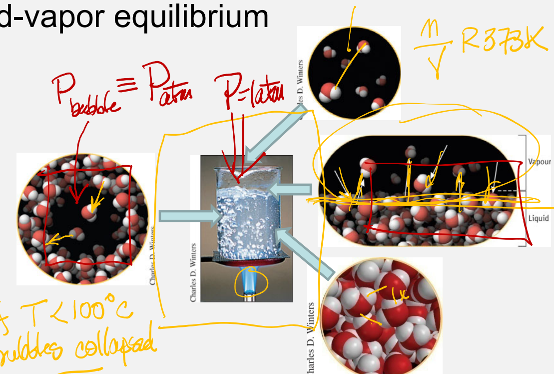
Liquid-vapor equilibrium



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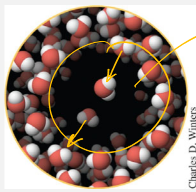
Vapor pressure and boiling point

Boiling means "bubbles".

Bubbles are pure vapor of the liquid.

Bubbles form only if they are able to hold back the liquid walls.

This means bubbles only exist if the vapor pressure is the same as the pressure acting on the liquid surface.



$P_{vapor} = P_{on\ the\ liquid}$

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[TP] Bubbles in a pot of boiling water contain …

0% 1. Only $O_2(g)$ and $N_2(g)$
100% 2. Only $H_2O(g)$
0% 3. Only air
0% 4. $H_2O(g)$ and air
0% 5. All of the above equally
0% 6. None of the above

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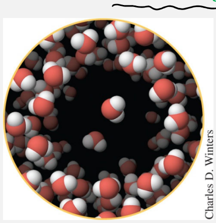
Vapor pressure and boiling point

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	Equilibrium Vapour Pressure (kPa)
Water, $H_2O(\ell)$	3.17
Ethanol, $C_2H_5OH(\ell)$	7.87
Hexane, $C_6H_{14}(\ell)$	20.2
Bromine, $Br_2(\ell)$	28.7
Acetone, $CH_3COCH_3(\ell)$	30.8
Carbon disulfide, $CS_2(\ell)$	48.2
Diethyl ether, $C_2H_5OC_2H_5(\ell)$	71.7

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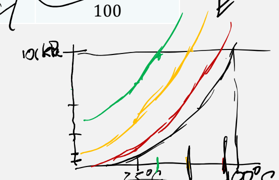
[TP] The order of normal boiling points (lowest to highest) is …

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

100% 1. diethyl ether < acetone < ethanol
0% 2. ethanol < acetone < diethyl ether
0% 3. acetone < diethyl ether < ethanol
0% 4. ethanol < diethyl ether < acetone
0% 5. something else
0% 6. Not sure



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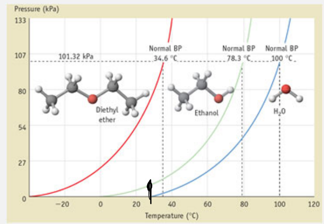
Vapor pressure and boiling point

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, $CH_3C(O)CH_3$	3: 30.8	3: 56
Diethyl ether, $(CH_3CH_2)_2O$	4: 71.7	4: 35
Ethanol, CH_3CH_2OH	2: 7.87	2: 78
Water, H_2O	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_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?

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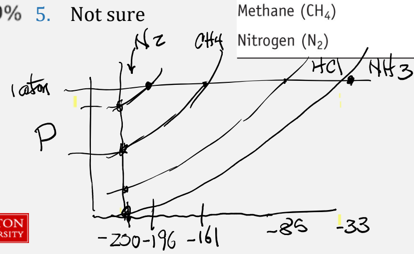
[TP] The substance with the lowest vapor pressure substances at −200°C is ...

0% 1. CH_4
100% 2. NH_3
0% 3. HCl
0% 4. N_2
0% 5. Not sure

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



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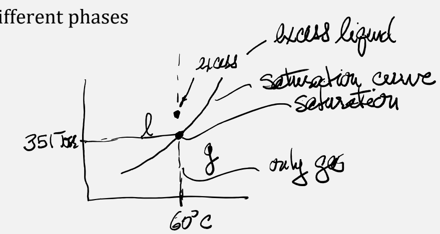
Phase diagrams

Lines of P versus T at which different phases are present at the same time.

That is, values of P and T at which different phases are in equilibrium.



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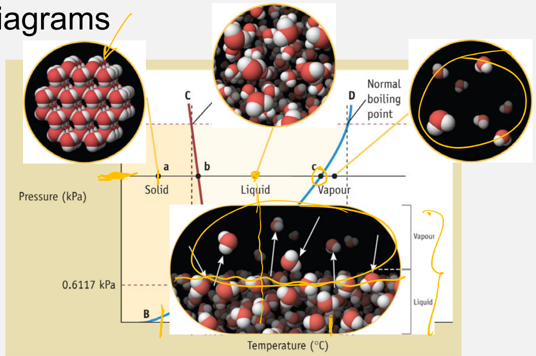
Phase diagrams



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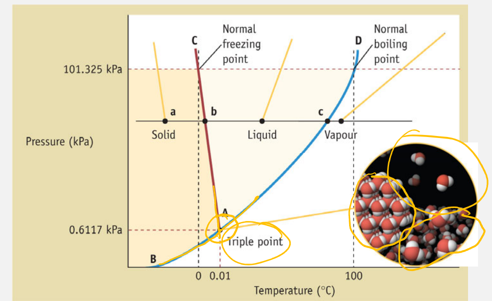
What about the intersection marked "A"



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Triple point

Liquid tert-butyl alcohol, $C(CH_3)_3OH$, can boil and freeze at the same time...

http://goo.gl/4K1SR

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Changes of phase

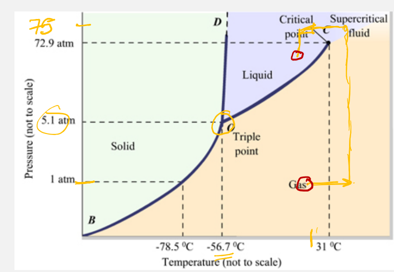
CO_2 gas at 1 atm, 25°C

is heated to 1 atm, 35°C;

then compressed to 75 atm, 35°C;

then cooled to 75 atm, 25°C;

then expanded to 65 atm, 25°C.



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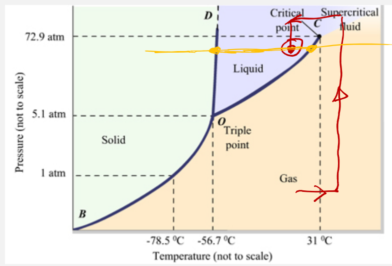
[TP] CO_2 gas at 1 atm, 25°C
is heated to 1 atm, 35°C;
then compressed to 75 atm, 35°C;
then cooled to 75 atm, 25°C;
then expanded to 65 atm, 25°C.
At this point, the CO_2 will be a ...



0% 1. gas
0% 2. supercritical fluid
100% 3. liquid
0% 4. solid
0% 5. Not sure

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