What will be covered in Chap 11?

1st Compare gases, liquids & solids

2nd Then REVIEW bonding forces

3rd Next INTERmolecular forces

4th Then Properties of liquids

5th Phase changes & diagrams

And last, but not least Vapor pressure

What is the difference between

H_2O (gas)

H_2O (liquid)

H_2O (solid)

The _____ of the molecules of water

CHEMICAL BONDING

INTRA molecular

vs

INTER molecular

Bonding

Review of Basic Chemical Bonding

Chemical Bonds are Formed _____ Elements

These Bonds are called _____ molecular forces

CHEMICAL BONDS THAT ARE FORMED ***BETWEEN ELEMENTS*** BY INTERACTION OF _____ OF ELECTRONS

1. **IONIC BOND**
2. **POLAR COVALENT BOND**
3. **COVALENT BOND**
4. **COORDINATE COVALENT**

1. IONIC BOND

COMPLETE _____ OF AN ELECTRON FROM ONE ELEMENT TO ANOTHER

Na^+ Cl^-

#2. COVALENT BOND

EQUAL _____ **OF**

A PAIR OF ELECTRONS

BETWEEN ATOMS

Examples:

Hydrogen	Nitrogen	Oxygen	Fluorine	Methane
H-H	N-N	O-O	F- F	$C\text{-}H_4$

#3. POLAR COVALENT BOND

_____ INTERACTION OF A PAIR OF ELECTRONS BETWEEN ATOMS

- **For Example**

Hydrogen Chloride

H → Cl

#4. **COORDINATE COVALENT**

- An Ordinary Covalent Bond – **_____** Atom Donates One Electron
- A Coordinate Covalent Bond - **_____** **ELECTRONS COME** FROM ***ONE*** ELEMENT ONLY

  Examples: NH_4^+ and NH_3-BCl_3

BOND POLARITY AND ELECTRONEGATIVITY

A POLAR BOND Has a DIPOLE

$\delta+ \; H \rightarrow Cl \; \delta-$

A DIPOLE CONSISTS OF SEPARATED _____ AND _____ CHARGES

What type of intra molecular bond is formed in

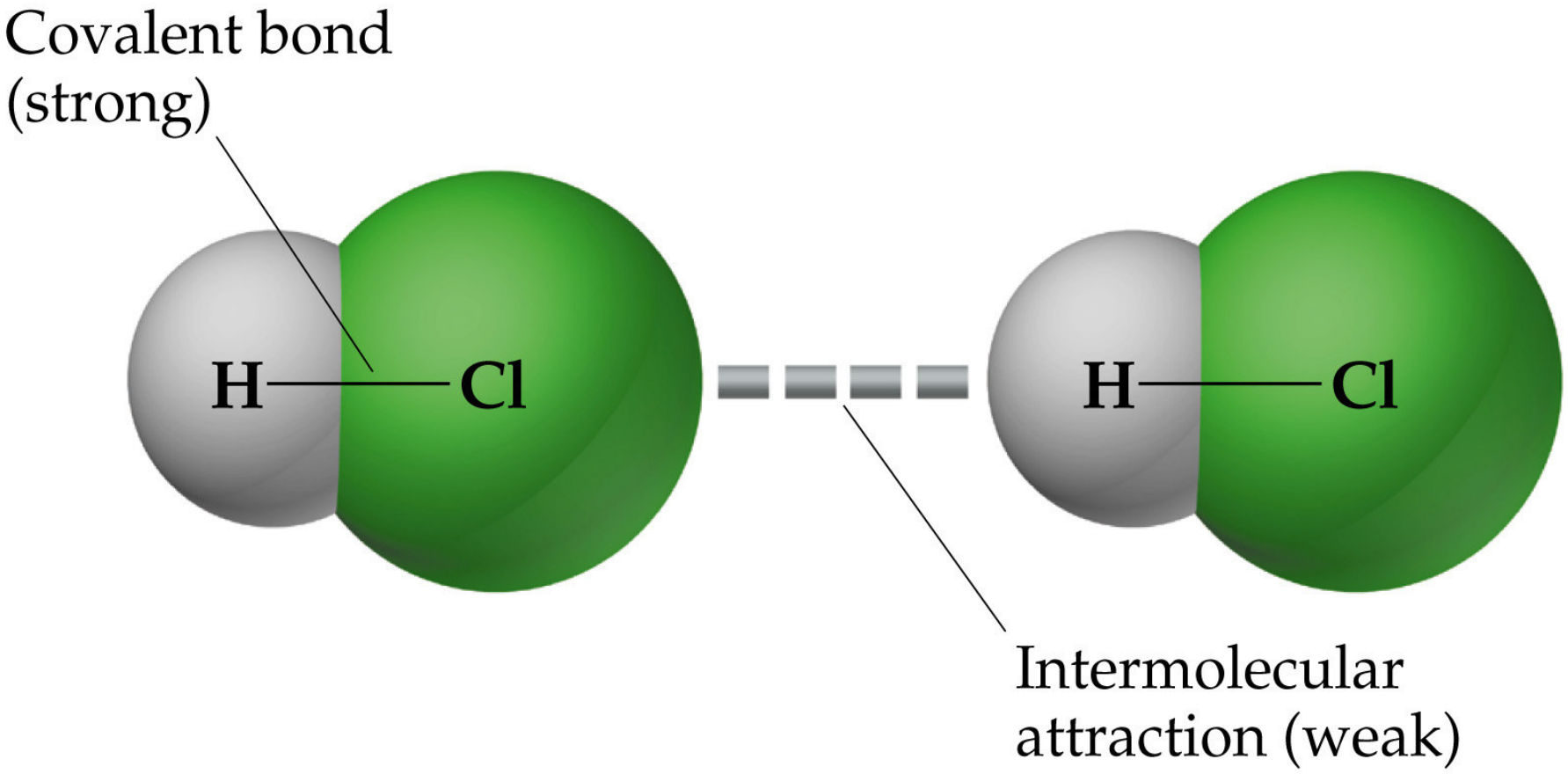
1. Magnesium oxide
2. Oxygen
3. Carbon disulfide
4. Iodide monobromide
5. Methane
6. Helium

“Bonds” Formed Between MOLECULES

Are due to

_____molecular Forces

Intermolecular Forces



INTER molecular Forces

Much weaker than _____molecular forces.

Several types of forces:

1. Ion–dipole
2. Dipole–dipole
3. London Forces => Instantaneous induced–dipole (dispersion forces)
4. Hydrogen “bonds.”

INTERmolecular forces

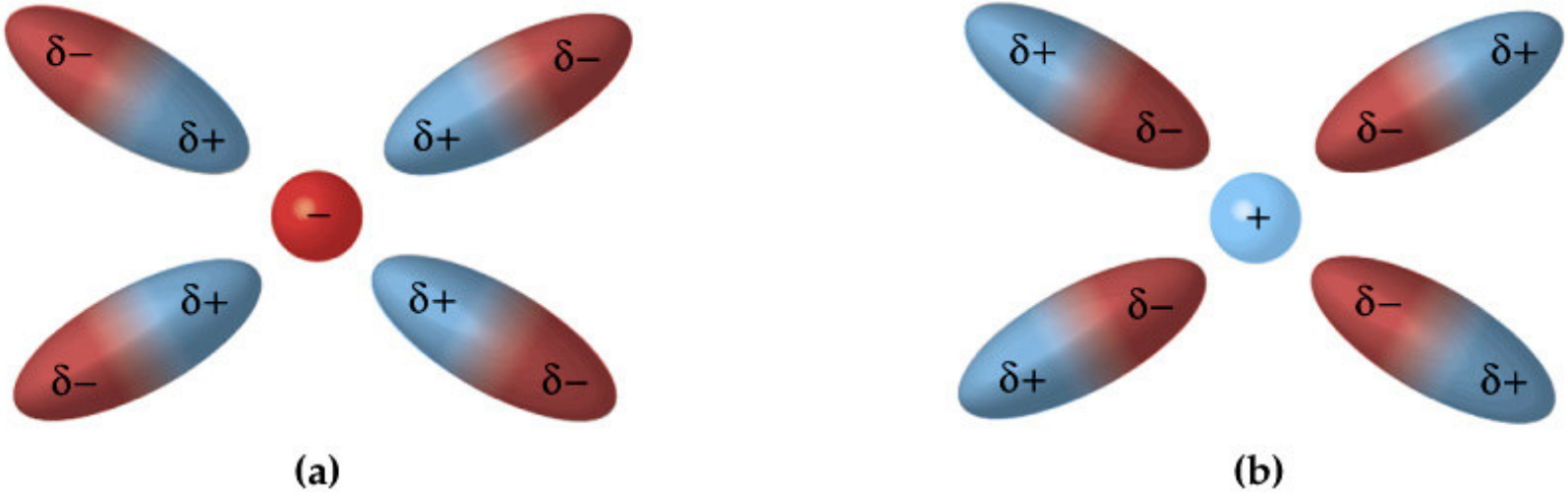
The attractive forces **between** molecules and ions determine bulk properties of matter.

Van der Waals forces

- Dipole-dipole interactions
- Hydrogen bonding
- London dispersion forces

Intermolecular Forces

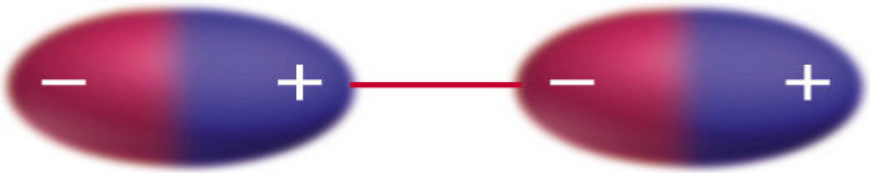
- **Ion–Dipole**: Between polar molecules & ions.

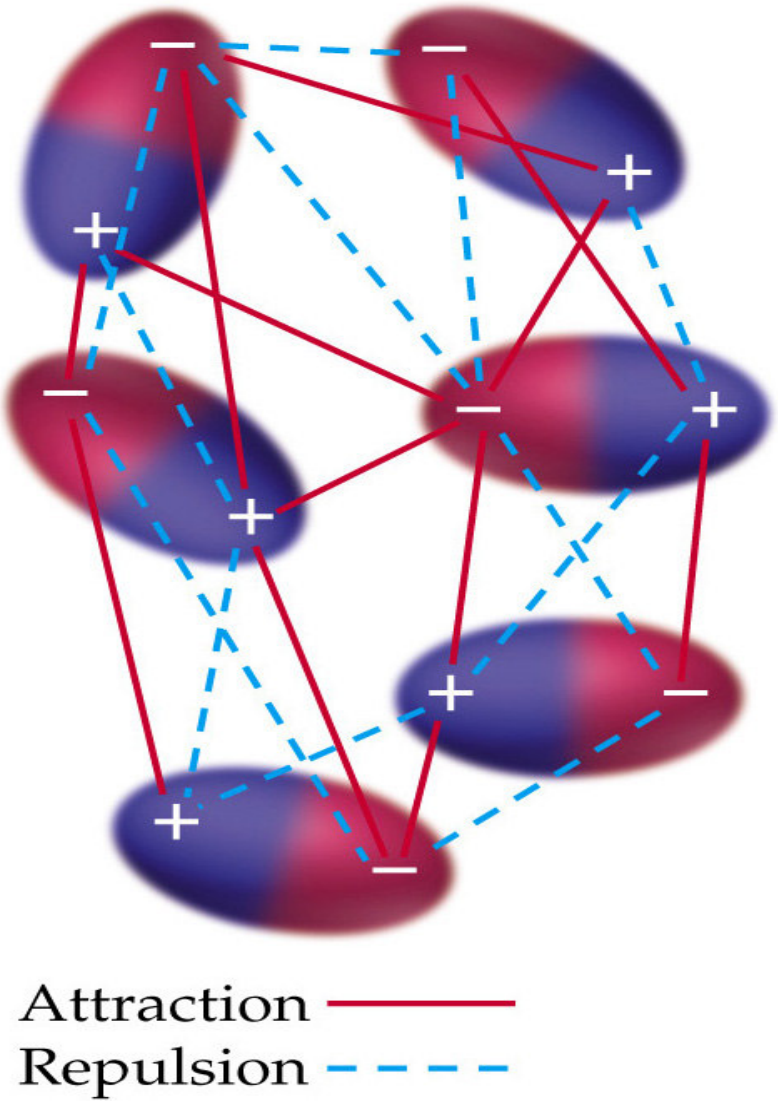


Next **Dipole–Dipole**:

Between polar molecules.

Dipole-Dipole Forces





DIPOLE-DIPOLE INTERACTIONS

Substance	Molecular Weight (amu)	Dipole Moment μ (D)	Boiling Point (K)
Propane, $CH_3CH_2CH_3$	44	0.1	231
Dimethyl ether, CH_3OCH_3	46	1.3	248
Methyl chloride, CH_3Cl	50	1.9	249
Acetaldehyde, CH_3CHO	44	2.7	294
Acetonitrile, CH_3CN	41	3.9	355

THE MORE POLAR THE MOLECULE, THE HIGHER IS ITS BOILING POINT.

London Dispersion Forces

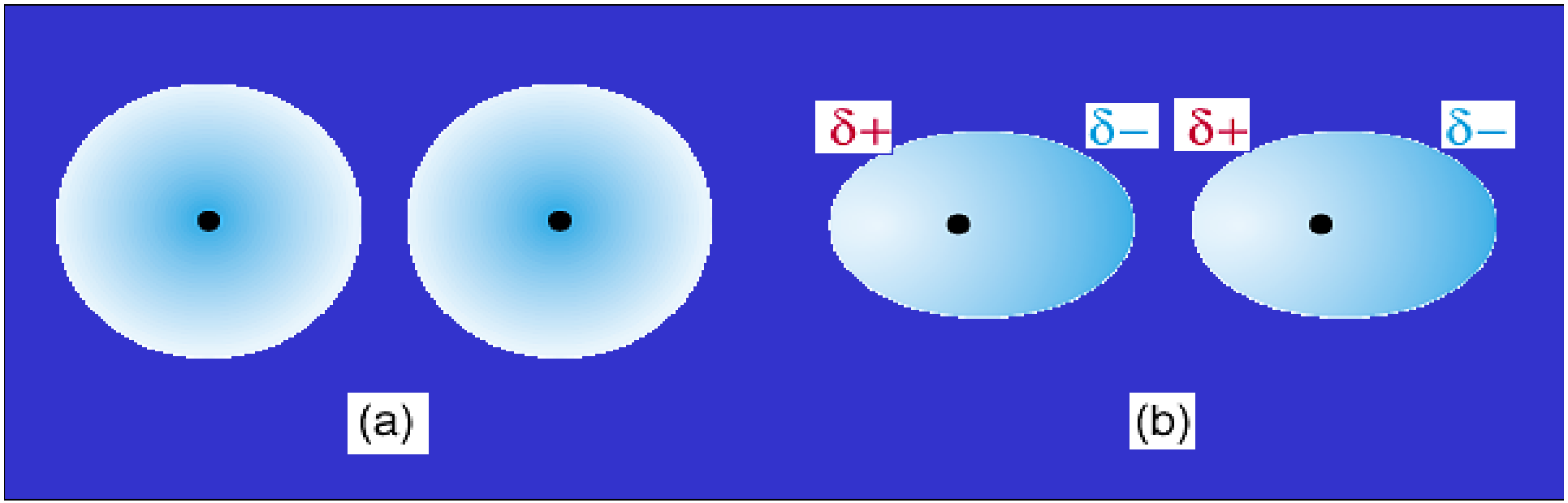
- Weakest of all intermolecular forces.
- For an instant, the electron clouds become distorted.
- In that instant a dipole is formed (called an instantaneous dipole)

INTERMOLECULAR FORCES

- **Polarizability** is the ease with which an electron cloud can be deformed.
- The **larger** the molecule (the greater the number of electrons) the more polarizable.
- **London** dispersion forces increase as molecular weight increases.

London Dispersion Forces:

Attraction is due to instantaneous, ***temporary dipoles*** formed due to electron motions.



FACTORS AFFECTING LONDON FORCES

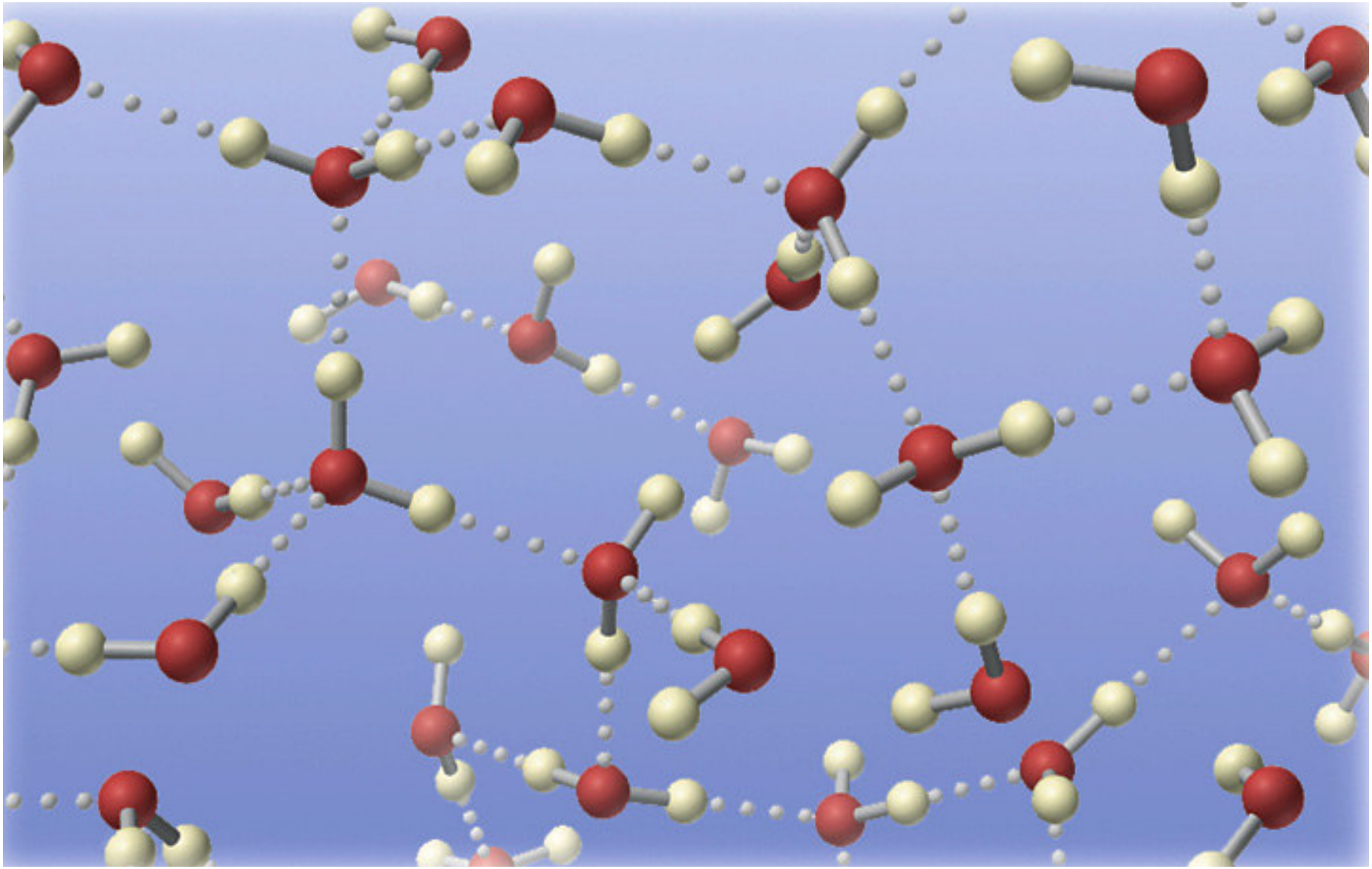
Halogen	Molecular Weight (amu)	Boiling Point (K)	Noble Gas	Molecular Weight (amu)	Boiling Point (K)
F_2	38.0	85.1	He	4.0	4.6
Cl_2	71.0	238.6	Ne	20.2	27.3
Br_2	159.8	332.0	Ar	39.9	87.5
I_2	253.8	457.6	Kr	83.8	120.9
			Xe	131.3	166.1

THE STRENGTH OF DISPERSION FORCES TENDS TO INCREASE WITH INCREASED MOLECULAR WEIGHT.

LAST {but not least}

HYDROGEN BONDING

Hydrogen Bonding in Water



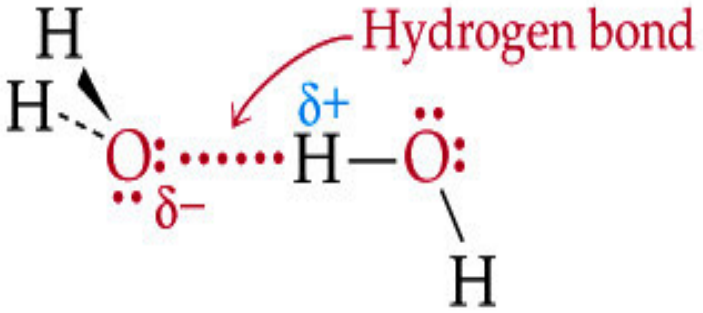
HYDROGEN BOND

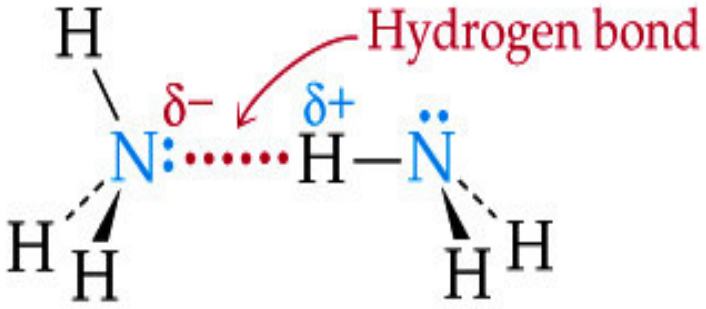
Between molecules containing
N–H, O–H, or F–H groups,

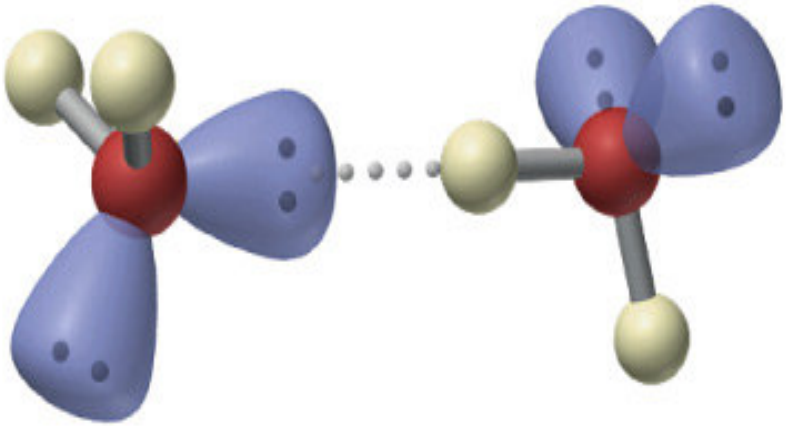
AND AN ELECTRONEGATIVE

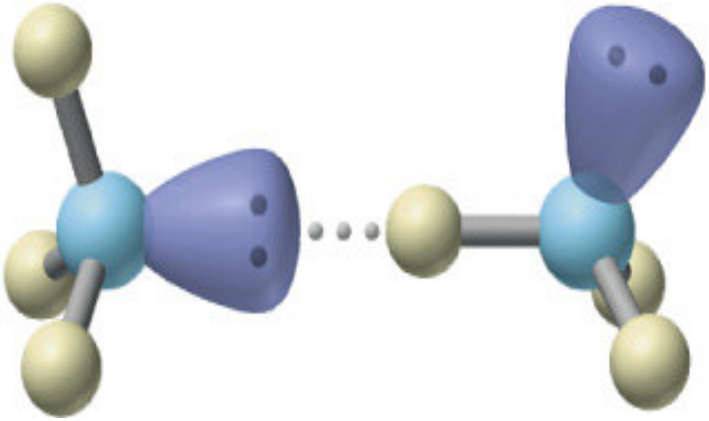
O, N, or F atom

HYDROGEN BOND

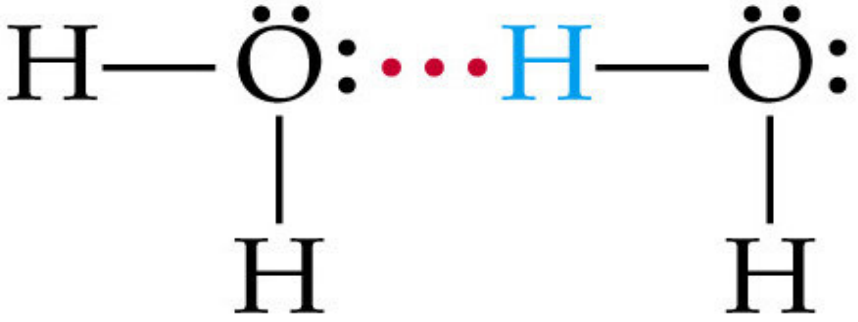


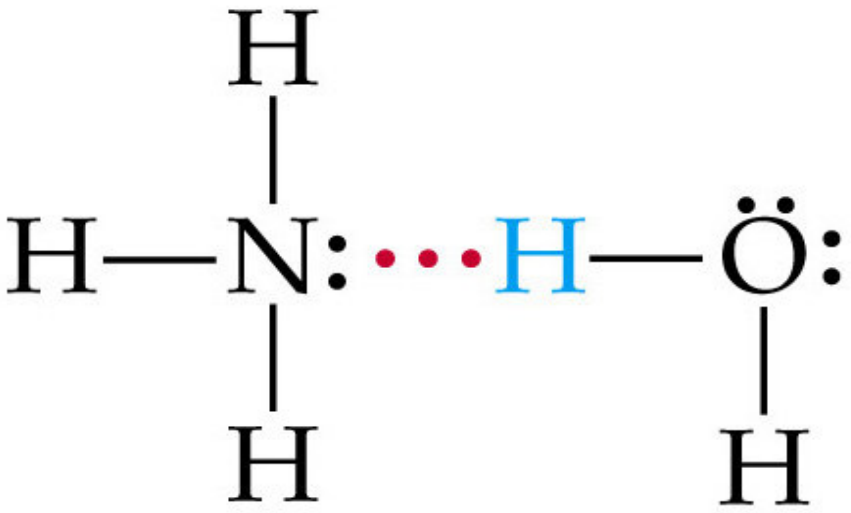


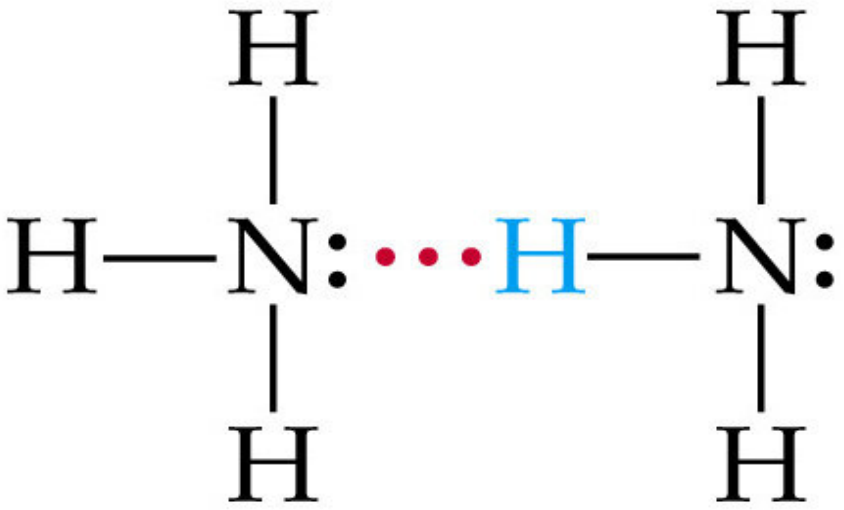


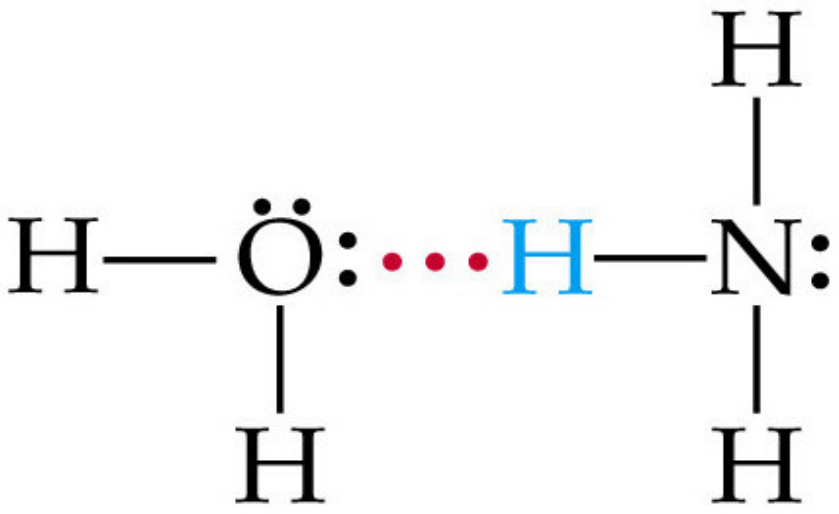


HYDROGEN BONDING









Comparison of Intermolecular Forces

FORCE	***STRENGTH***
Ion - Ion	
Ion - Dipole	
Hydrogen Bonding	
Dipole – Dipole	
London Dispersion	***Decrease***

11.9 Describe the intermolecular forces that must be overcome to convert each of the following from a liquid to a gas

(a) Br_2

(b) CH_3OH

(c) H_2S

(a) London forces only

(b) Hydrogen bonding
dipole – dipole forces
and **London** forces

(c) Dipole –dipole forces
and **London** forces

Strength of intermolecular interactions

1. Dipole – dipole attractions INCREASE in magnitude as the dipole moment of the molecule increases

2. Dispersion forces INCREASE in strength with increasing MOLECULAR WEIGHT

Which of the following has the largest intermolecular dispersion forces

He	or Kr	_____
Cl_2	or I_2	_____
Br_2	or O_2	_____
HCl	or HBr	_____
CH_4	or CCl_4	_____

INTERMOLECULAR FORCES

& Liquid Properties

Viscosity

&

Surface Tension

Viscosity

The resistance of a liquid to flow

A liquid **flows** by sliding
molecules over each other

The _____ the intermolecular forces, the higher the viscosity.

Liquids like molasses, honey and heavy motor oil do not flow readily

They have a high viscosity and are said to be

VISCOUS

Liquids like water do flow readily

They have a LOW viscosity and are said to be

MOBILE

TABLE 11.4 Viscosities of a Series of Hydrocarbons at 20°C

Substance	Formula	Viscosity (cP)
Hexane	$CH_3CH_2\,CH_2CH_2CH_2CH_3$	0.326
Heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	0.409
Octane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	0.542
Nonane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	0.711
Decane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	1.42

Viscosity Increases with Molecular Weight

Which of the following has the highest viscosity ?

(a) **Ethanol** CH_3- CH_2- OH

(b) **Ethylene Glycol**

$$\begin{array}{l} CH_2 - OH \\ | \\ CH_2 - OH \end{array}$$

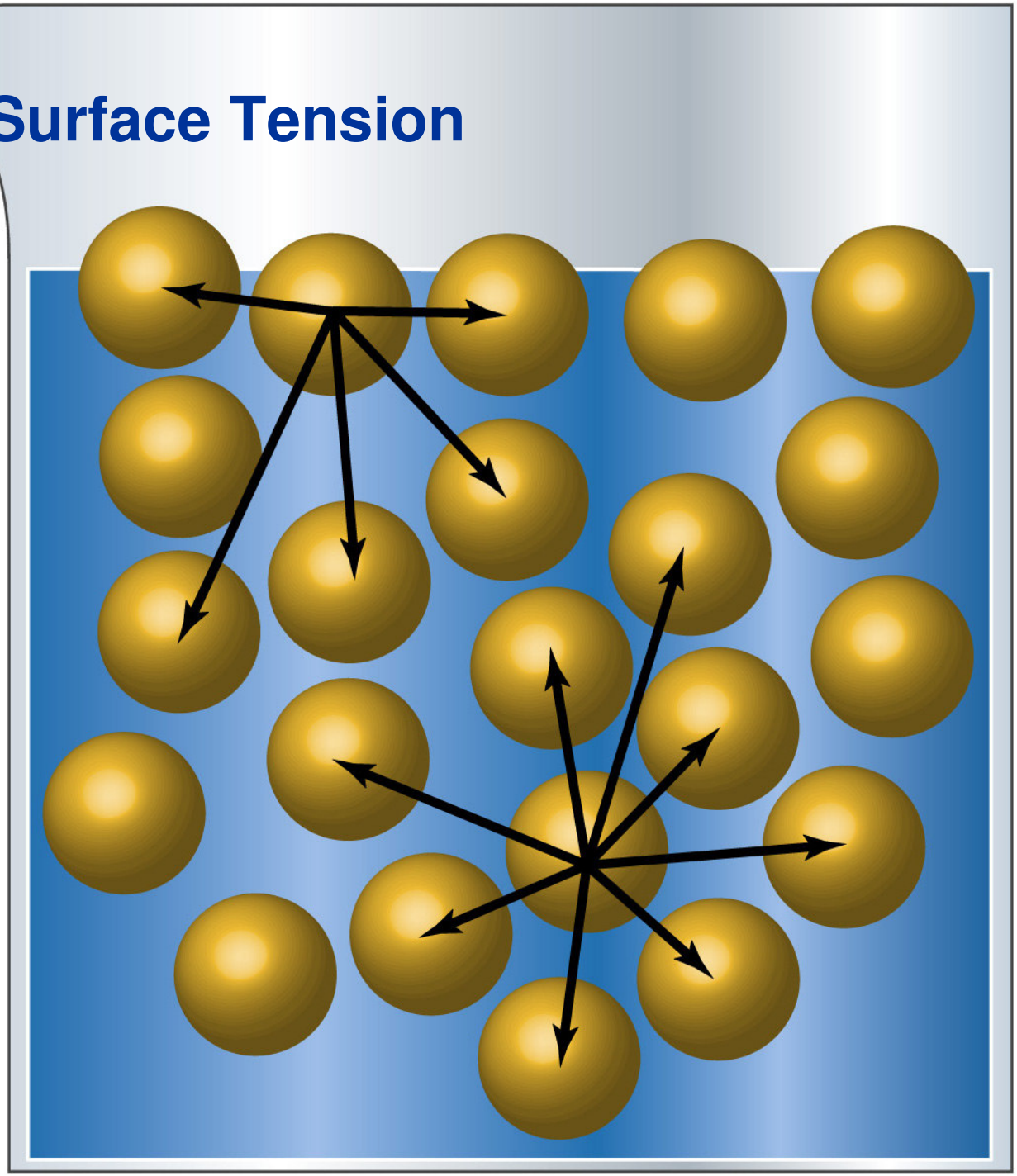
(c) **Glycerol**

$$\begin{array}{l} CH_2 - OH \\ | \\ CH - OH \\ | \\ CH_2 - OH \end{array}$$

The Stronger the forces, the Greater the viscosity

Surface Tension

different intermolecular forces experienced by molecules in the interior of a liquid and those on the surface.



SURFACE TENSION

- the amount of energy required to ***increase the surface area*** of a liquid.

- ***Cohesive forces*** bind molecules to each other.

- ***Adhesive forces*** bind molecules to a surface.

11.24 Distinguish between ADHESIVE and COHESIVE forces

Adhesive ***forces*** bind molecules to a surface.

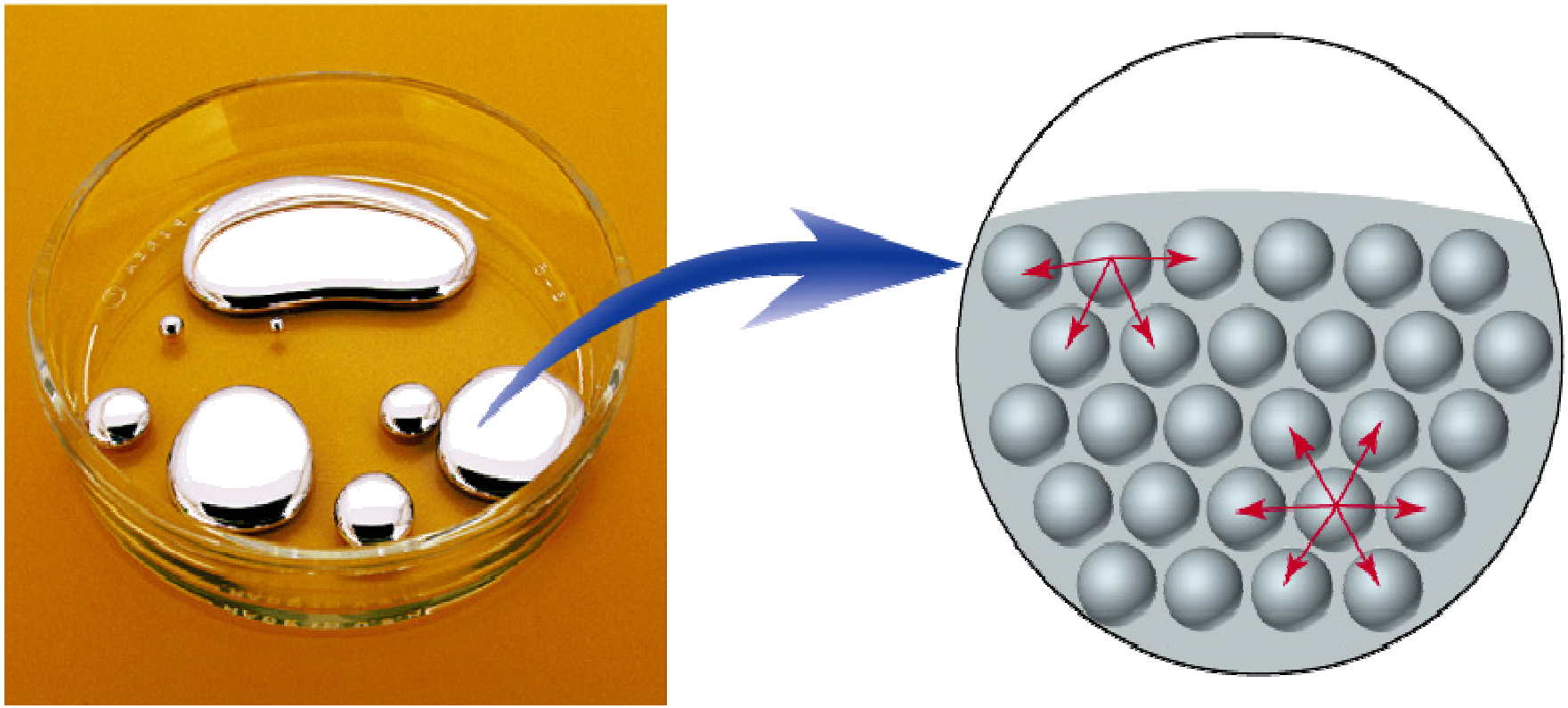
Cohesive ***forces*** bind molecules to each other

11.24 Do viscosity and surface tension reflect adhesive **or** cohesive forces?

Viscosity and surface tension reflect attractive forces among molecules in a liquid .

Therefore _____

Surface Tension is the resistance of a liquid to spread out and increase its surface area.



Predict which of the following liquids has greater surface tension

(a) Ethanol CH_3- CH_2- OH

(b) Dimethyl ether CH_3 O CH_3

MENISCUS {shape of the liquid surface

U

If ***adhesive forces*** are greater than cohesive forces, the liquid surface is attracted to its container more than the bulk molecules

Ω

If ***cohesive forces*** are greater than adhesive forces, the meniscus is curved downwards.

Problem 11.24 Explain U-shaped meniscus for water

Adhesive forces between water and glass are stronger than **cohesive** forces in water

Explain Ω-shaped meniscus for mercury

Adhesive forces between mercury and glass are weaker than **cohesive** forces in mercury

BOILING
and
Vapor Pressure

Boiling

Normally the boiling point will **increase** as you move **down** a group (increase in molecular weight)

EXCEPTIONS

HF ; H_2O ; NH_3 Why ?

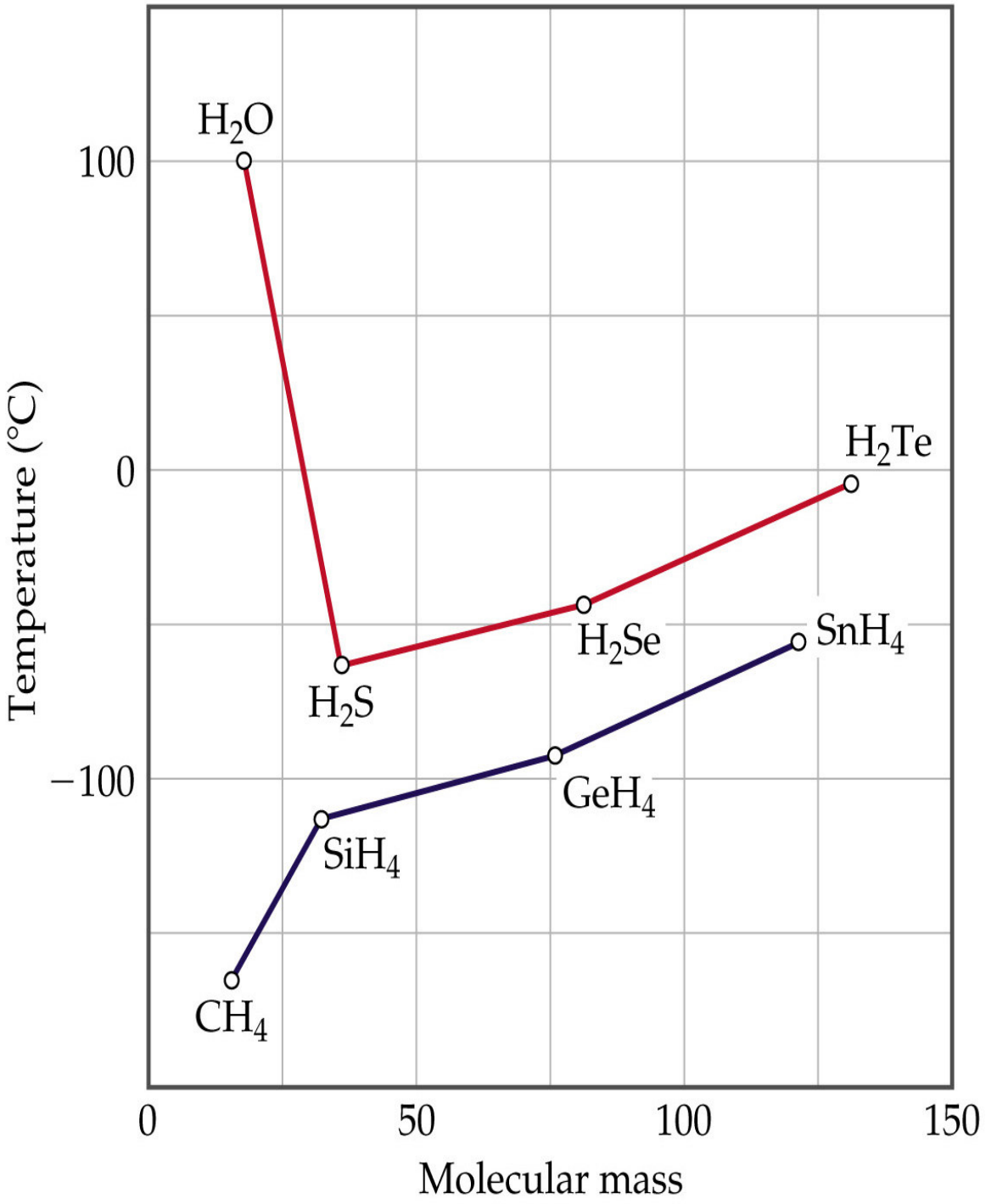


TABLE 11.2 Molecular Weights, Dipole Moments, and Boiling Points of Several Simple Organic Substances

Substance	Molecular Weight (amu)	Dipole Moment μ (D)	Boiling Point (K)
Propane, $CH_3CH_2CH_3$	44	0.1	231
Dimethyl ether, CH_3OCH_3	46	1.3	248
Methyl chloride, CH_3Cl	50	1.9	249
Acetaldehyde, CH_3CHO	44	2.7	294
Acetonitrile, CH_3CN	41	3.9	355

If you lived in Alaska, which of the following natural gases would you keep in an outdoor storage tank in winter?

(a) Methane CH_4

(b) Propane C_3H_8

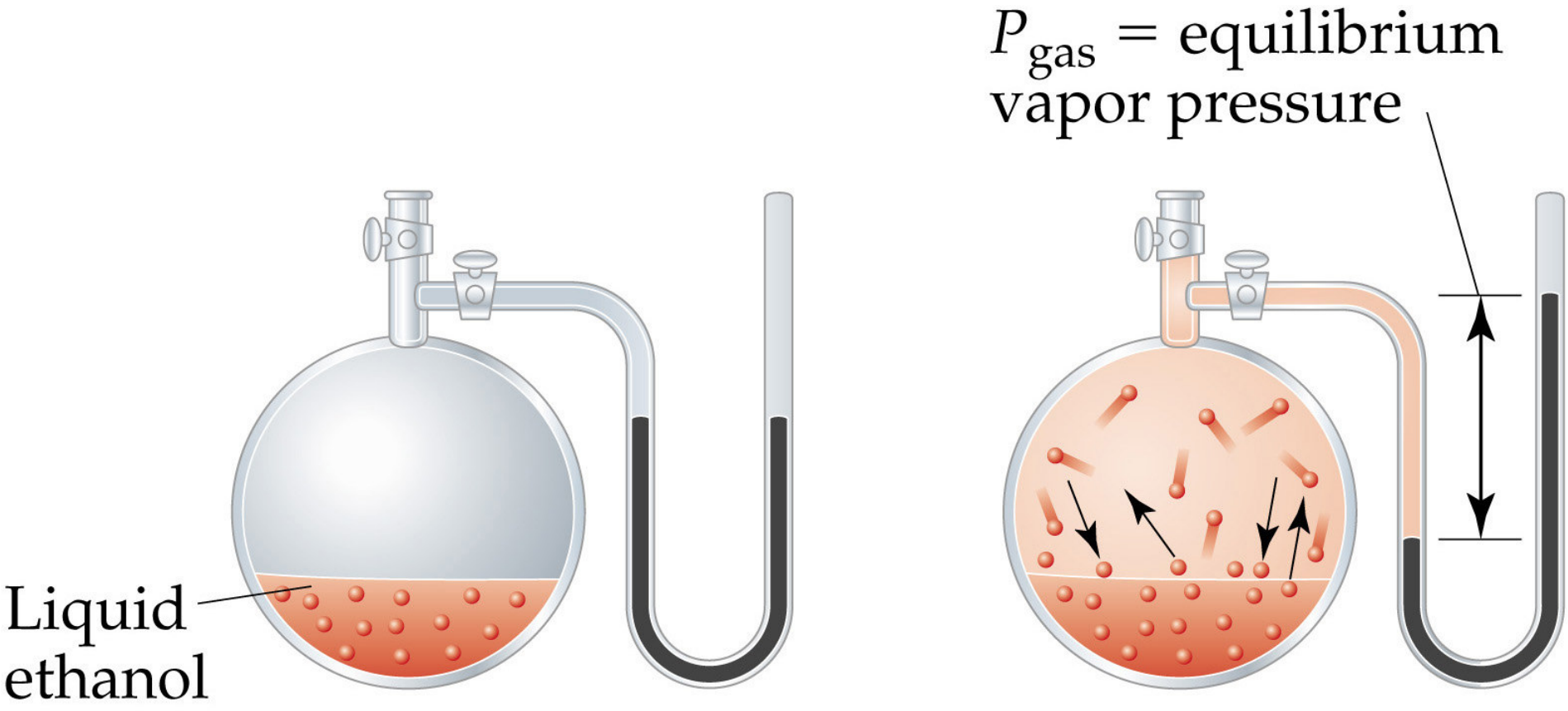
(c) Butane C_4H_{10}

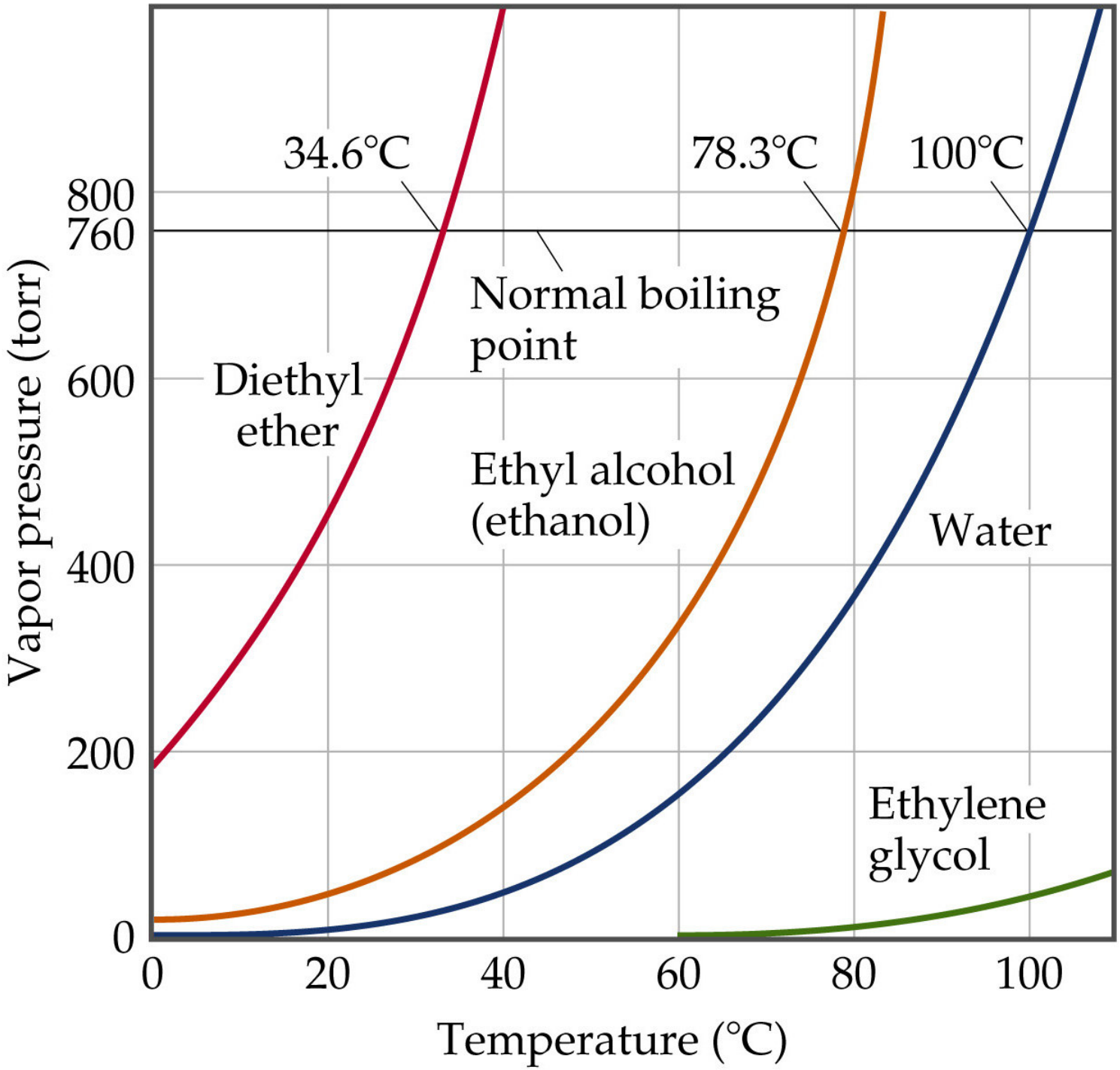
Vapor Pressure on the Molecular Level

Some of the molecules on the surface of a liquid have enough energy to escape the attraction of the bulk liquid.

These molecules move into the gas phase

Vapor Pressure




34.6°C
78.3°C
100°C
800
760
600
400
200
0
Vapor pressure (torr)
Normal boiling point
Diethyl ether
Ethyl alcohol (ethanol)
Water
Ethylene glycol
0
20
40
60
80
100
Temperature (°C)

Vapor Pressure and Boiling Point

- **Liquids boil when the external pressure equals the vapor pressure.**

Normal boiling point is the boiling point at 760 mmHg (1 atm).

- **At high pressures the boiling point of water is greater than at 1 atm**

Problem 11.39 Place the following substances in order of increasing volatility

CH_4 _____

CBr_4 _____

CH_2Cl_2 _____

CH_3Cl _____

$CHBr_3$ _____

CH_2Br_2 _____

Now for the rest of the story

Phase Changes

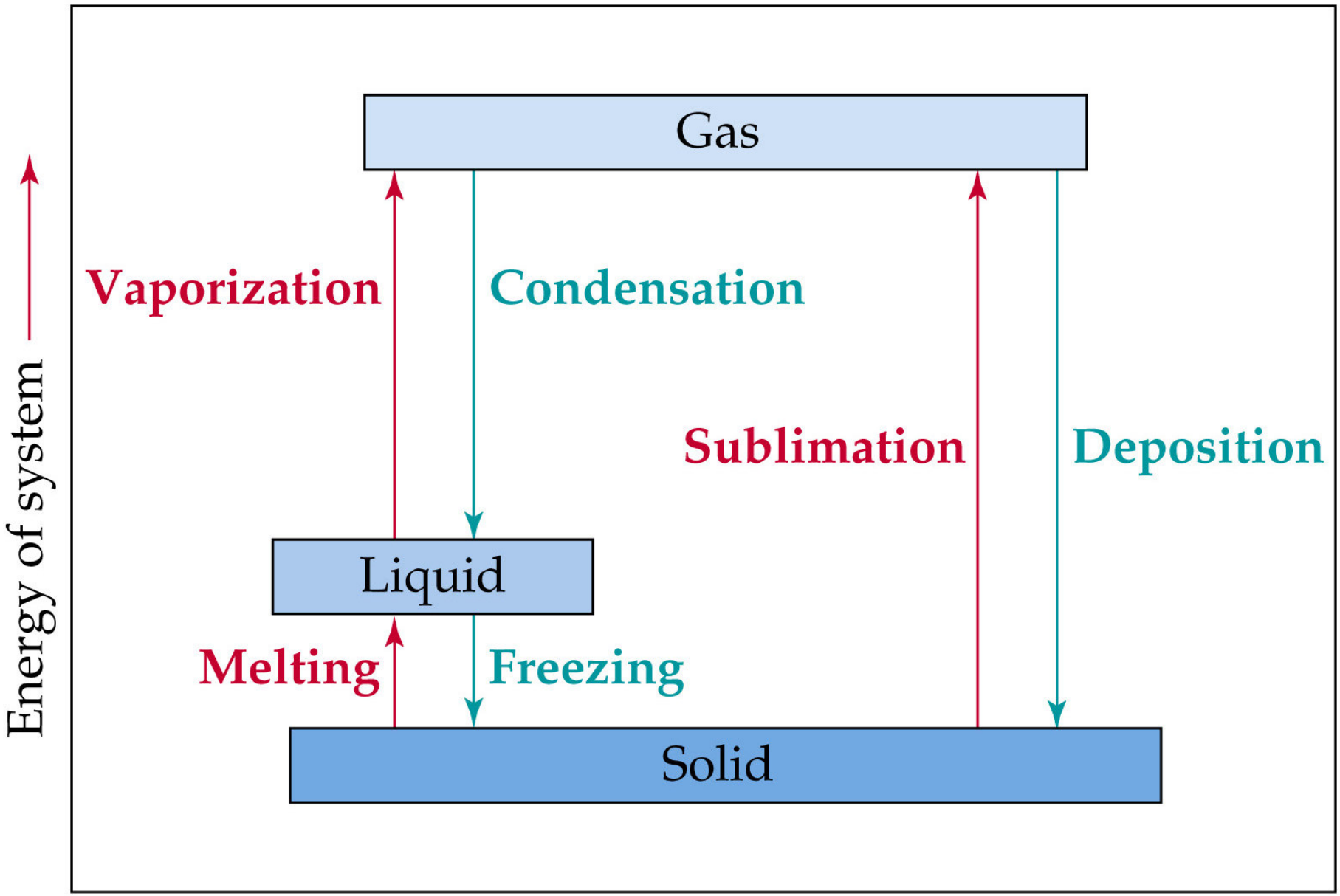
&

Phase Diagrams

PHASE

- A phase of a substance is a form of matter that is uniform throughout in chemical composition and physical state
- Phases : solid, liquid, gas
- Any Others ?????????

Phase Changes



PHASE CHANGES

Gas → Liquid	*Condensation*
Liquid → Gas	*Vaporization*
Solid → Gas	*Deposition*
Gas → Solid	*Sublimation*
Liquid → Solid	*Freezing* or Crystallization
Solid → Liquid	*Melting* or *Fusion*

PHASE DIAGRAMS

- A plot of **Pressure** vs **Temperature**

summarizing all equilibria between phases.

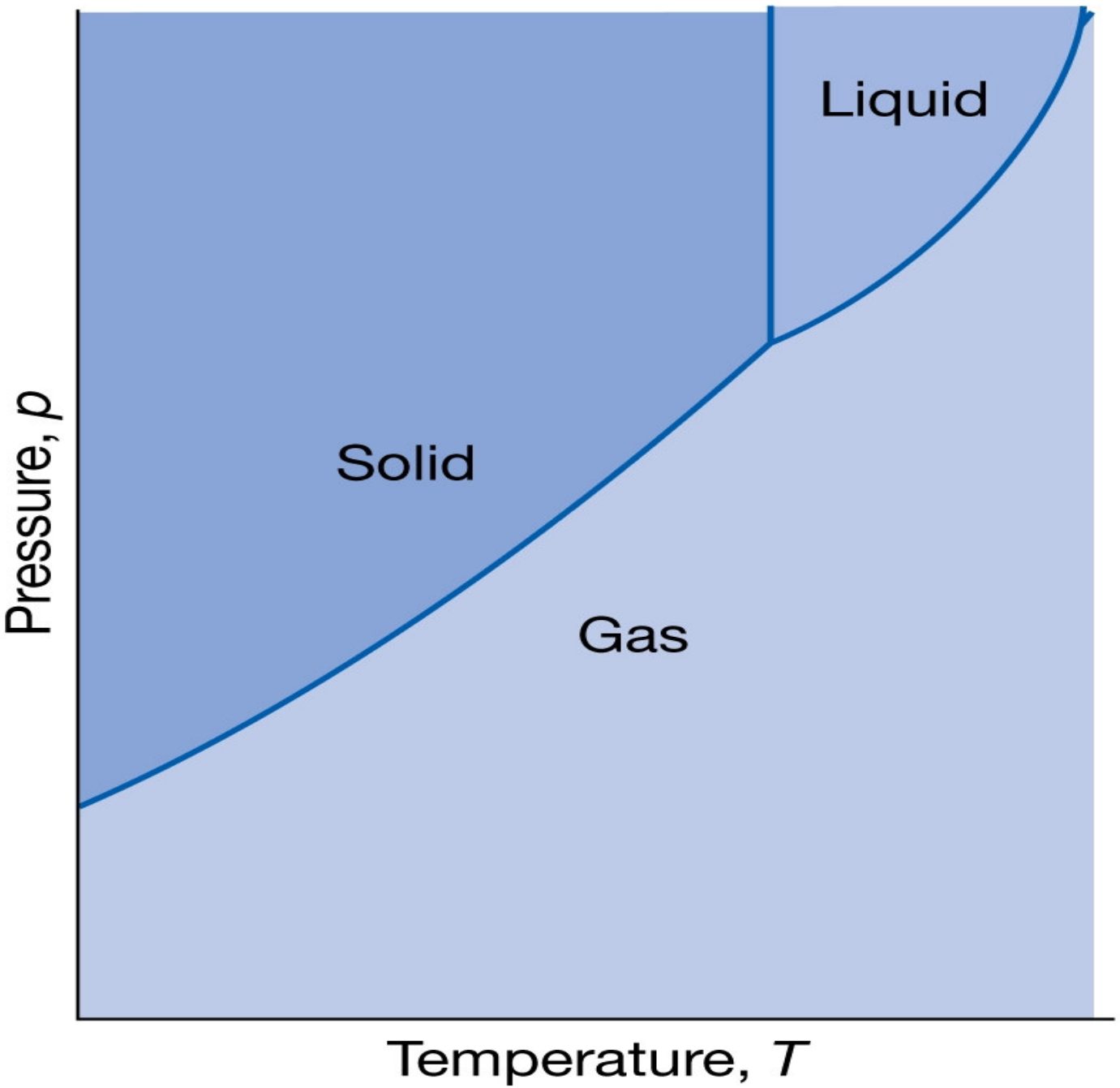
- Given a temperature and pressure,

Phase Diagrams tell us which phase will exist

- Any temperature and pressure combination

Not on a curve

represents a Single Phase.


Liquid
Solid
Gas
Pressure, p
Temperature, T

Terminology

- BOILING Point
  - NORMAL Boiling Point
- MELTING Point
  - NORMAL Melting Point
- TRIPLE Point
- CRITICAL Point

A Liquid boils when its vapor pressure equals the external pressure

- ***NORMAL*** Boiling Point

  The boiling point at 1 atm pressure

- ***NORMAL*** Melting Point

  The melting point at 1 atm pressure

Triple Point

- A unique combination of pressure and temperature at which gas, liquid **and** solid phases coexist in ***equilibrium***

Critical Point

A combination of

temperature and pressure

beyond which

a gas cannot be liquefied

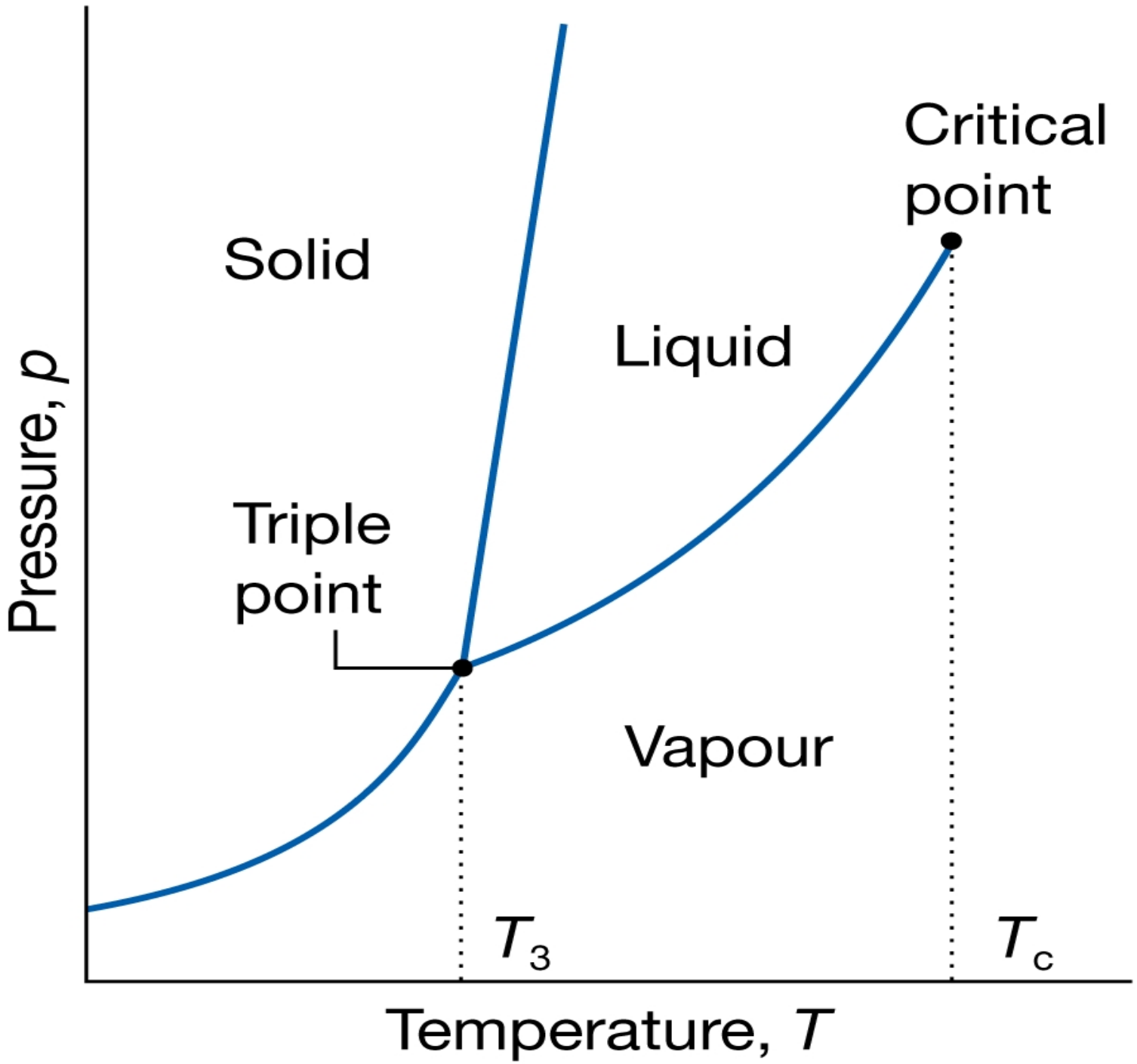
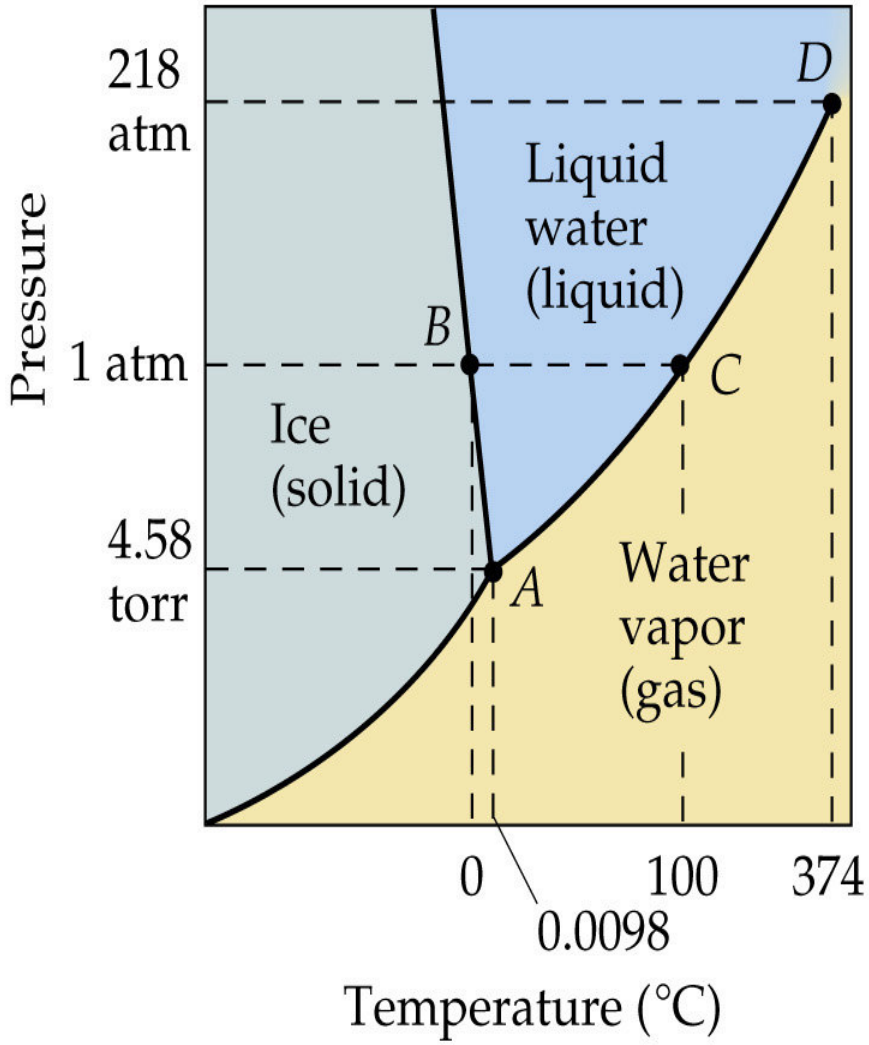
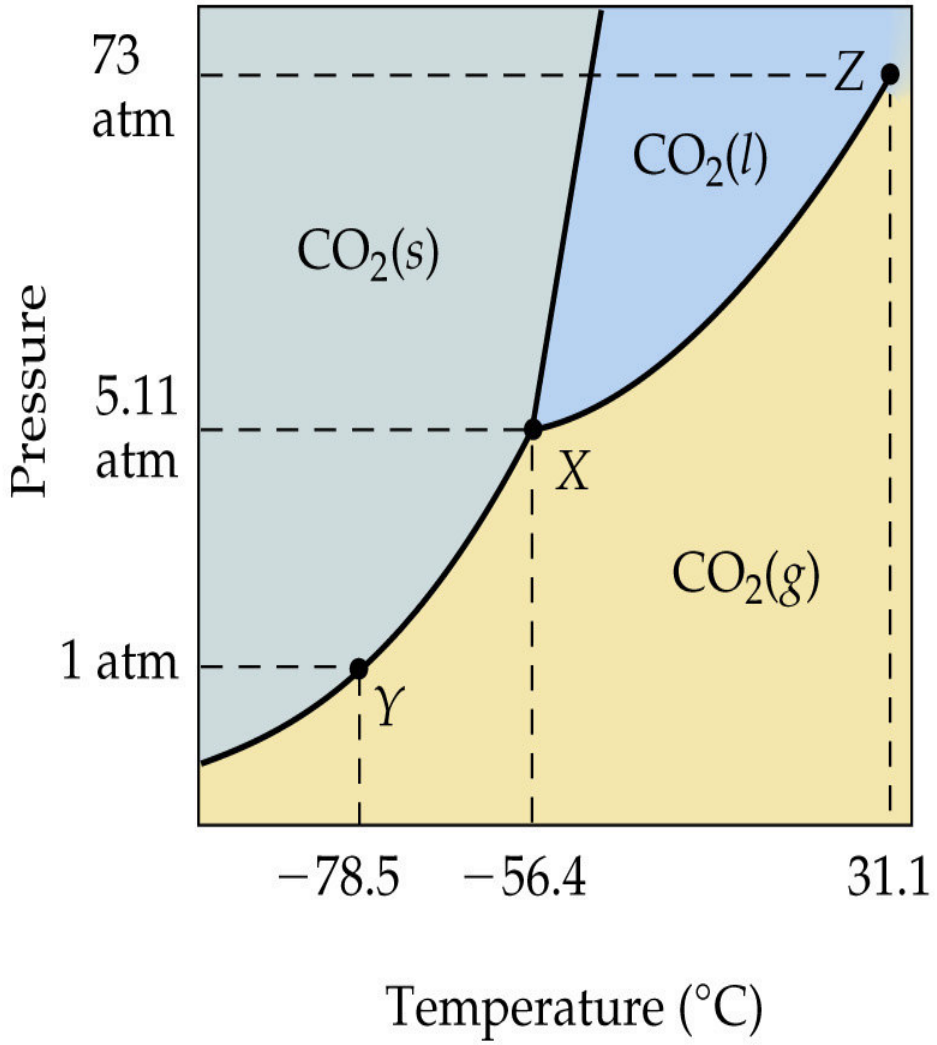

Critical
point
Solid
Liquid
Triple
point
Vapour
Pressure, p
T_3
T_c
Temperature, T

TABLE 11.5 Critical Temperatures and Pressures of Selected Substances

Substance	Critical Temperature (K)	Critical Pressure (atm)
Ammonia, NH_3	405.6	111.5
Phosphine, PH_3	324.4	64.5
Argon, Ar	150.9	48
Carbon dioxide, CO_2	304.3	73.0
Nitrogen, N_2	126.1	33.5
Oxygen, O_2	154.4	49.7
Propane, $CH_3CH_2CH_3$	370.0	42.0
Water, H_2O	647.6	217.7
Hydrogen sulfide, H_2S	373.5	88.9

The Phase Diagrams of H_2O and CO_2





Features of a phase diagram

- **Triple point:** temperature and pressure at which all three phases are in equilibrium.
- **Vapor-pressure curve:** generally as pressure increases, temperature increases.
- **Critical point:** critical temperature and pressure for the gas.
- **Melting point curve**: as pressure increases, the solid phase is favored if the solid is more dense than the liquid.
- **Normal melting point:** melting point at 1 atm.

Water:

- The melting point curve slopes to the left because ice is less dense than water.
- Triple point occurs at 0.0098°C and 4.58 mmHg.
- Normal melting (freezing) point is 0°C.
- Normal boiling point is 100°C.
- Critical point is 374°C and 218 atm.

MORE TERMINOLOGY

- SUPERCRITICAL FLUID

&

- LIQUID CRYSTALS

SUPERCRITICAL FLUID

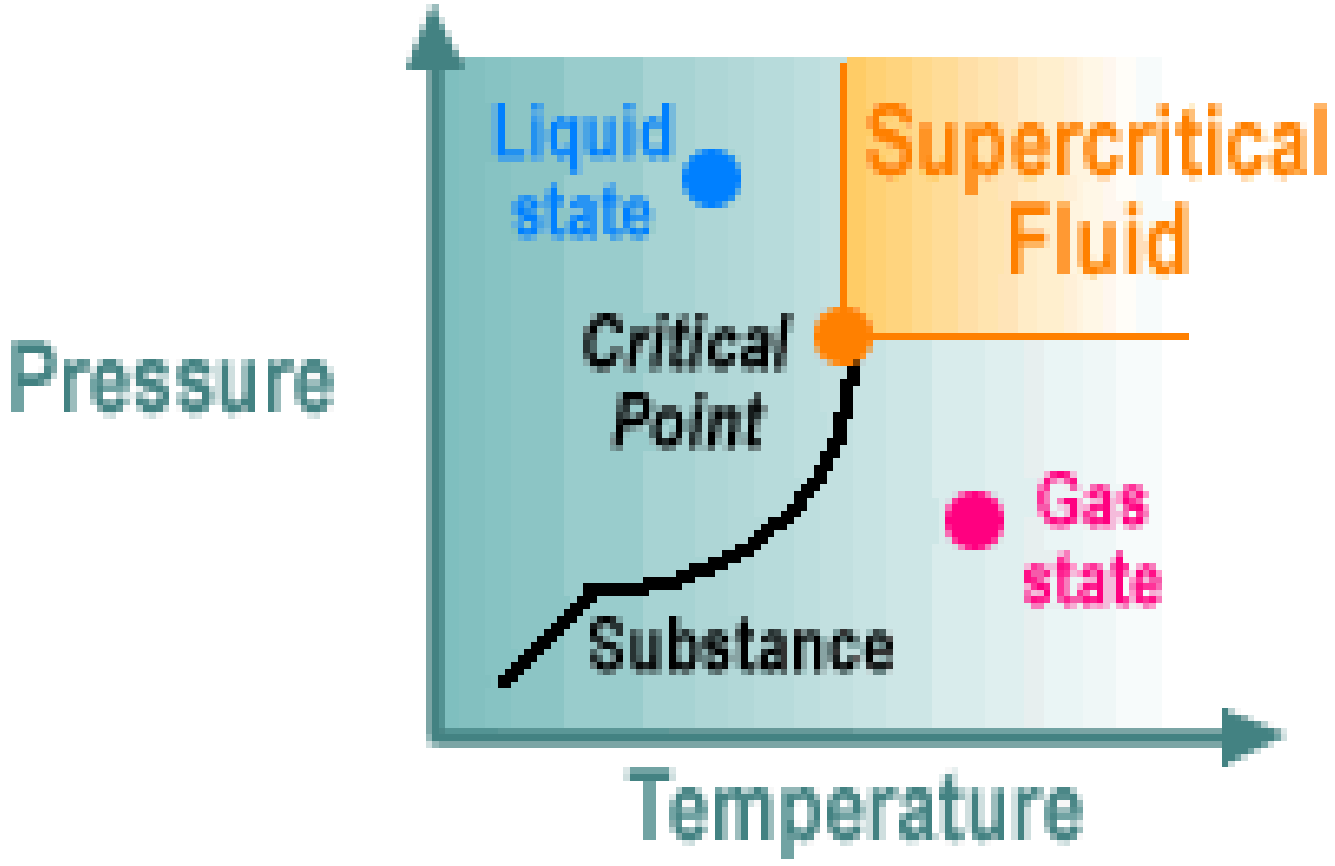
A state of matter beyond the critical point that is neither liquid nor gas

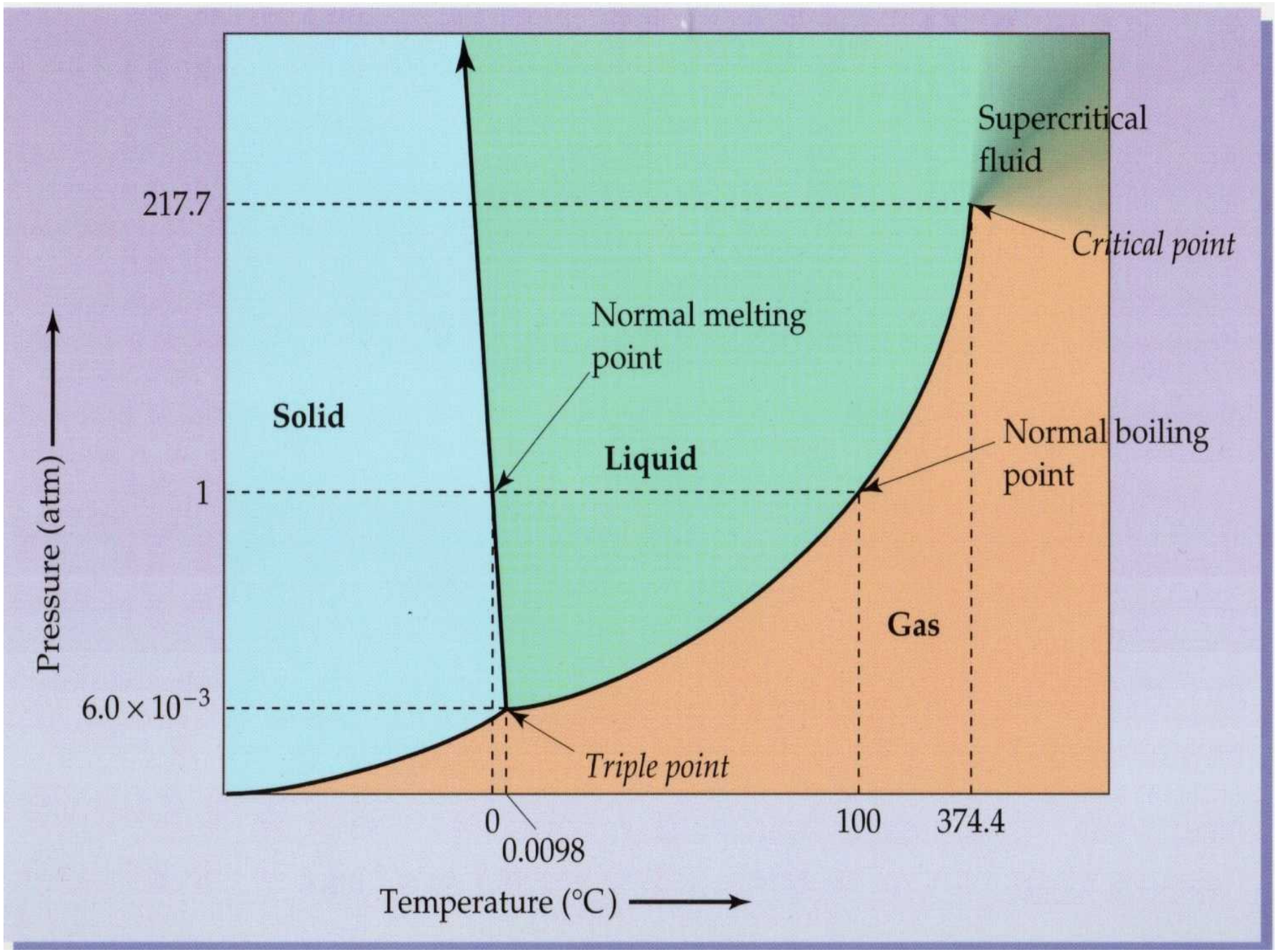
SUPERCRITICAL FLUIDS

At **ordinary** pressures a substance above its critical temperature behaves as an ordinary gas

At **higher** than critical pressures a substance above its critical temperature behaves more like a liquid than a gas and is best considered a supercritical fluid.

A substance becomes a supercritical fluid above its critical point of temperature and pressure




Supercritical fluid
217.7
Critical point
Normal melting point
Solid
Liquid
Normal boiling point
1
Gas
6.0×10^{-3}
Triple point
0
0.0098
100
374.4
Pressure (atm)
Temperature (°C)

Carbon dioxide is extremely attractive in industrial applications in the supercritical fluid area because it is

- the second most abundant solvent on earth
- the second least expensive solvent on earth
- It is non-flammable, and non-toxic.

End of Chapter 11