

CHEM103

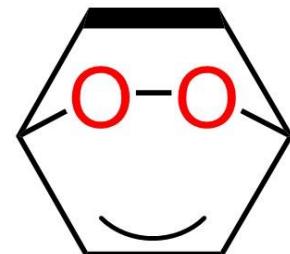
General Chemistry

Chapter 4: Reactions in Aqueous Solution



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Assignments 2-3 & Mid-term EXAM

Please either **print** the Answer Sheet or **use** your paper; **write down** your answers on your sheet/paper.

Please submit your assignments to any of your TAs or me during the classes. Or you can submit your assignment to the folder **outside room 520, research building 1** (anytime you like).

Homework 2

Due date: 17 Sep. (Sat)

Homework 3

Due date: 21 Sep. (Wed)

Mid-term EXAM

13 Nov. 10-12 AM (Sun)

Review on Chapter 3

Stoichiometry: Quantity of Substances; Balanced Chemical Formulas and Equations

Chemical Equations: Law of Conservation of Mass; Reactant & Product; States

Reaction Types: Combination, Decomposition & Combustion Reactions

Weights: Formula Weight; Molecular Weight; Percent Composition

Moles: Avogadro's Number; Molar Mass; Moles

Stoichiometric Calculations: Limiting Reactants; Excess Reagent; Theoretical/Actual Yields

Outline of Chapter 4

(Aqueous) Solution, Solvent, Solute

Dissociation: (Strong & Weak) Electrolyte; Conductivity

Precipitation: Solubility; Metathesis (Exchange) Reactions;
Molecular and (Net) Ionic Equations

Acid-Base: Arrhenius/Brønsted Acids & Bases; Neutralization;
Salt; Gas-forming Reactions

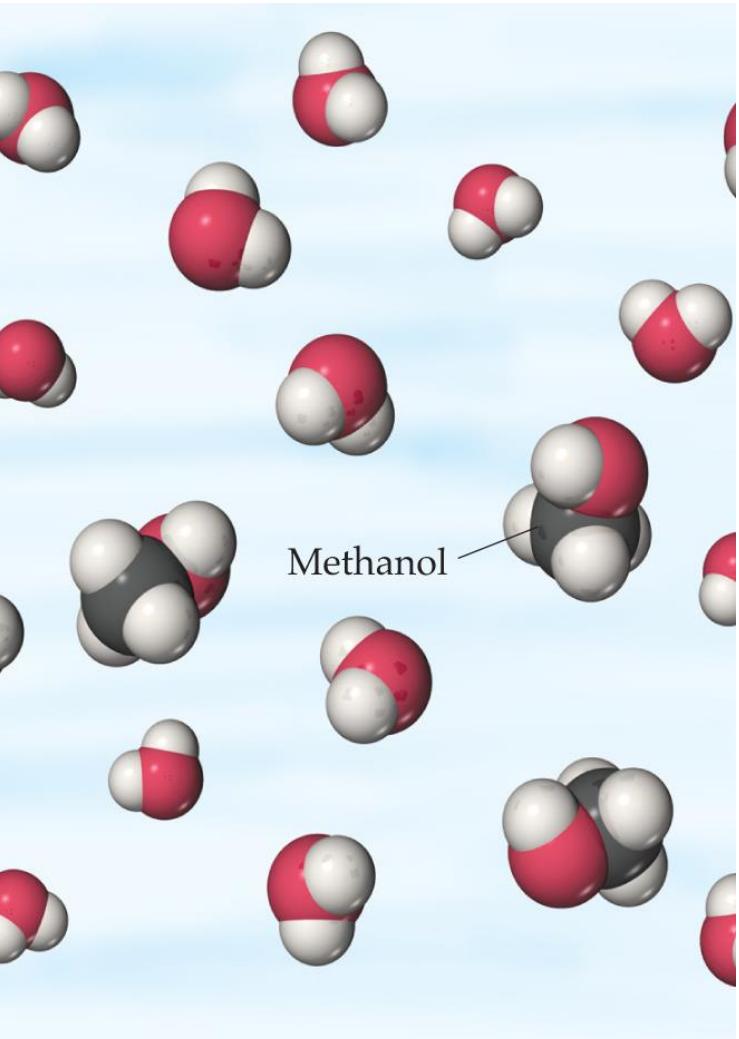
Oxidation-Reduction (Redox) Reaction: Oxidation
numbers; Displacement Reactions; Activity Series

Concentration: Molarity; Dilution; Titration

Solutions

(learn more from
Chapters 13 & 17)

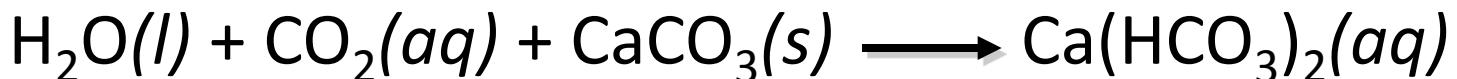
Solutions (溶液)



(b) Molecular substances like methanol, CH_3OH , dissolve without forming ions

- **Solutions:** **homogeneous mixtures** of **two or more** pure substances (one as **liquid** generally).
- The **solvent** (溶剂) is present in **greatest quantity** & acts as a **dissolving** medium. If **water** is the solvent, → **aqueous** solution.
- The other substances (**smallest amount**) are **solutes** (溶质) & dissolved (溶解) in the solvent.

e.g. a solution of NaCl
+ **Methanol** + H_2O (excess).

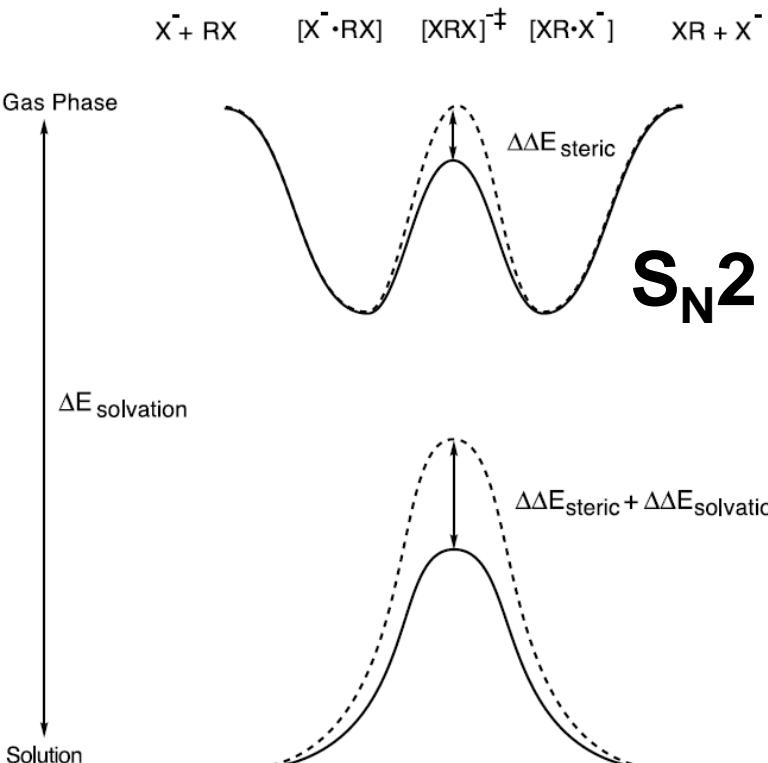


water + carbon dioxide + calcium carbonate →
calcium bicarbonate (or calcium hydrogen carbonate)

Effect of Solvent on Some Chemical Reactions

(Extra Info.) Energy surface (chapters 5 & 14)

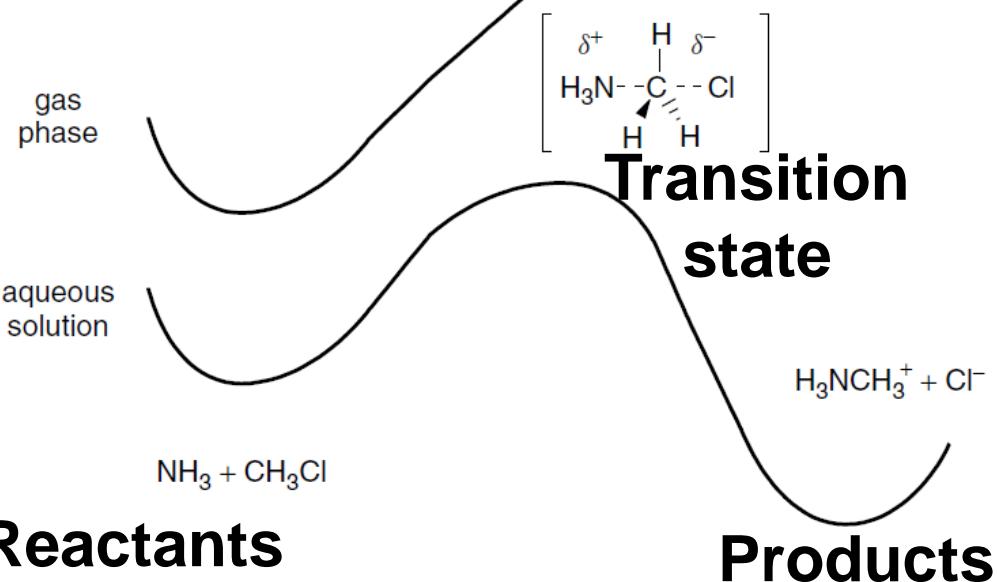
Menschutkin reaction



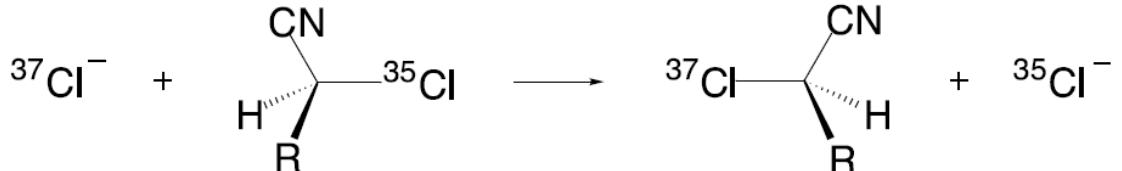
Energy

Reactants

Reaction coordinate



S_N2 reaction (nucleophilic substitution)
(Brauman *Science* 2002, 295, 2245)



R = CH₃

1

R = C(CH₃)₃

2

Anomalous (异常) or Unusual Properties of Water (Extra Info.)

1. Water has unusually high melting point. [Explanation]
2. Water has unusually high boiling point. [Explanation]
3. Water has unusually high critical point. [Explanation]

1. No aqueous solution is ideal. [Explanation]
2. D₂O and T₂O differ significantly from H₂O in their physical properties. [Explanation]
3. Liquid H₂O and D₂O differ significantly in their phase behavior. [Explanation]
4. H₂O and D₂O ices differ significantly in their quantum behavior. [Explanation]

1. The heat of fusion of water with temperature exhibits a maximum at -17 °C. [Explanation]
2. Water has over twice the specific heat capacity of ice or steam. [Explanation]
3. The specific heat capacity (C_P and C_V) is unusually high. [Explanation]

	COMPOUND	BOILING POINT	FREEZING POINT
H ₂ Te	Hydrogen Telluride	-4°C	-49°C
H ₂ Se	Hydrogen Selenide	-42°C	-64°C
H ₂ S	Hydrogen Sulfide	-62°C	-84°C
H ₂ O	Water	100°C	0 °C

<http://www1.lsbu.ac.uk/water/anmlies.html> (some were listed above)
http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Bulk_Properties/Unusual_Properties_of_Water

Is the **density** of **ice** always lower than that of liquid **water**?



H_2O ice in H_2O

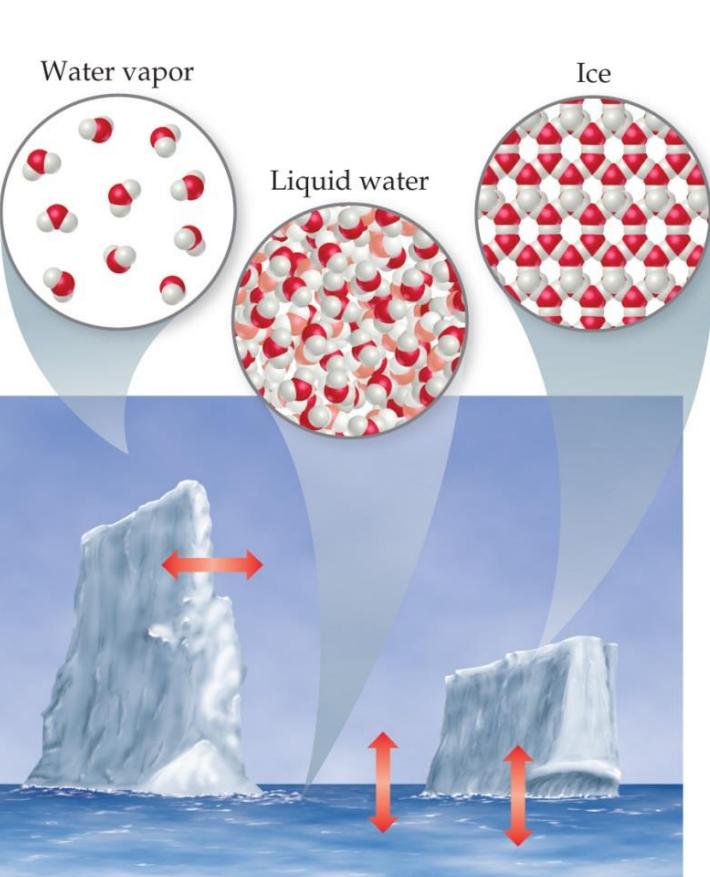
1 proton for H
(氢)



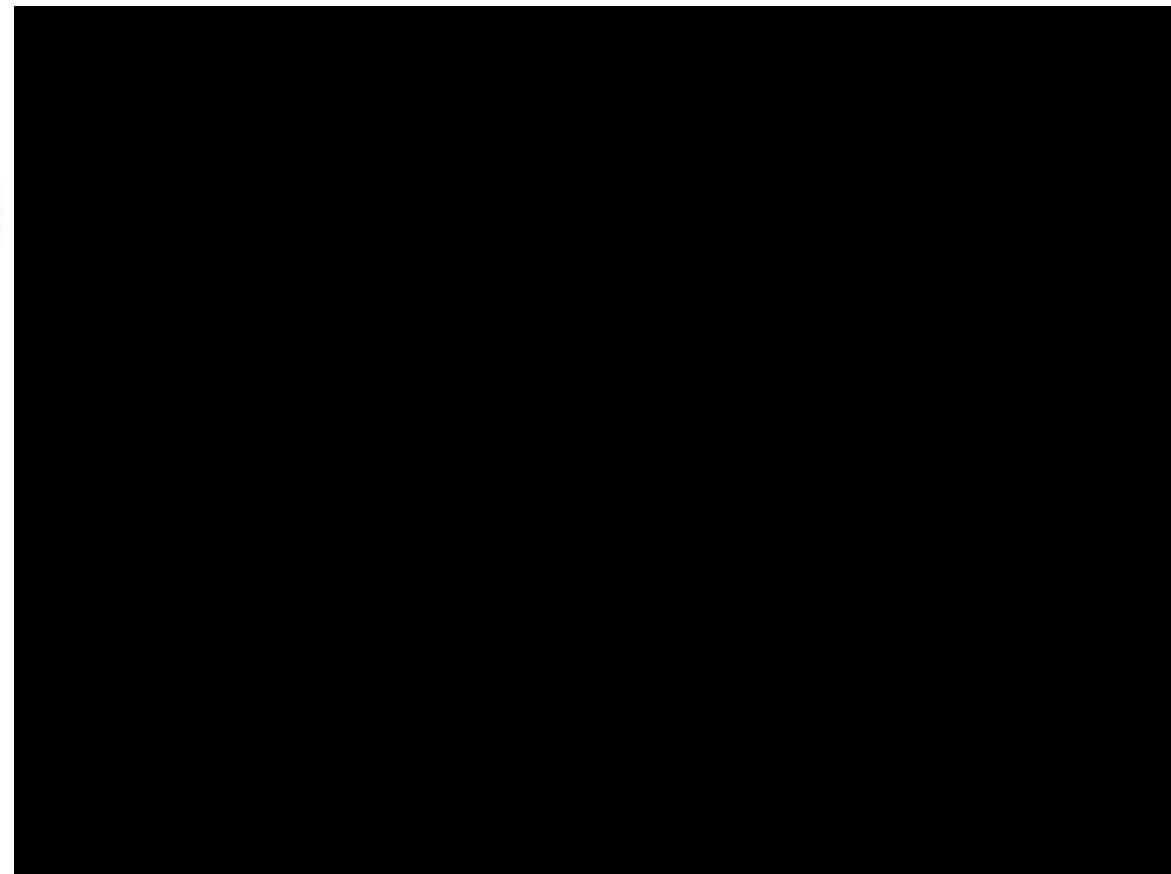
D_2O ice in H_2O

1 proton + 1 neutron
for deuterium (D, 氕)

Molecular Dynamics (分子动力学) (Computational Chemistry 计算化学): Molecular Scales (Extra Info.)

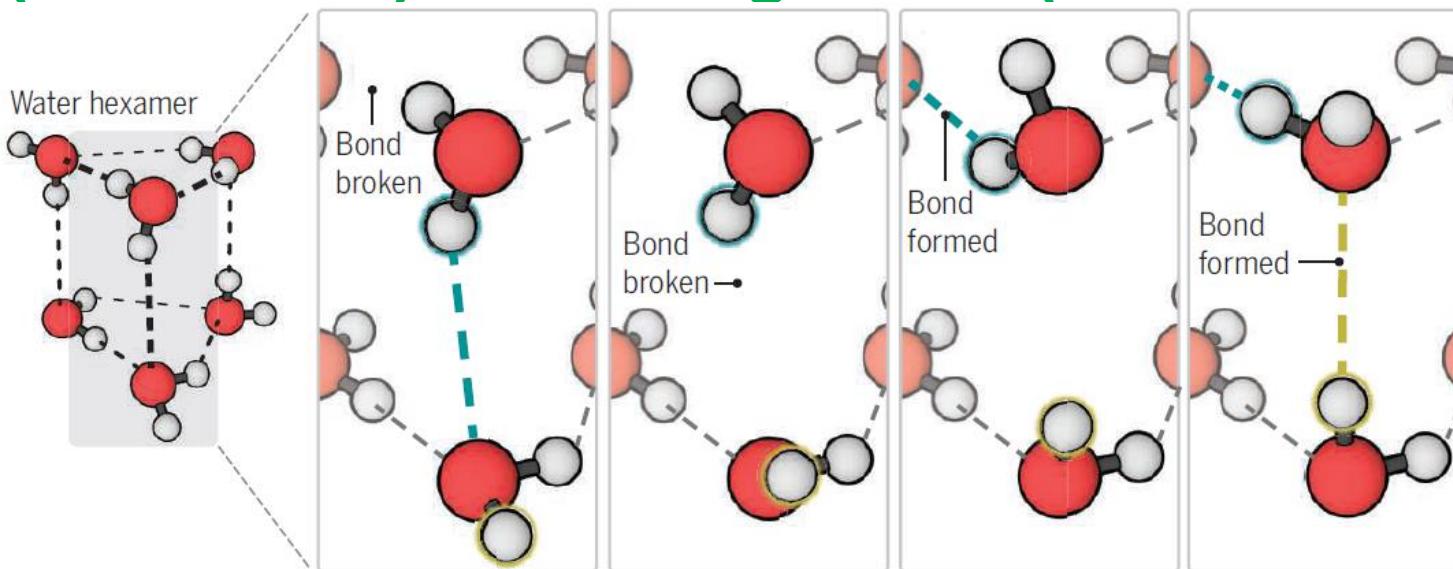


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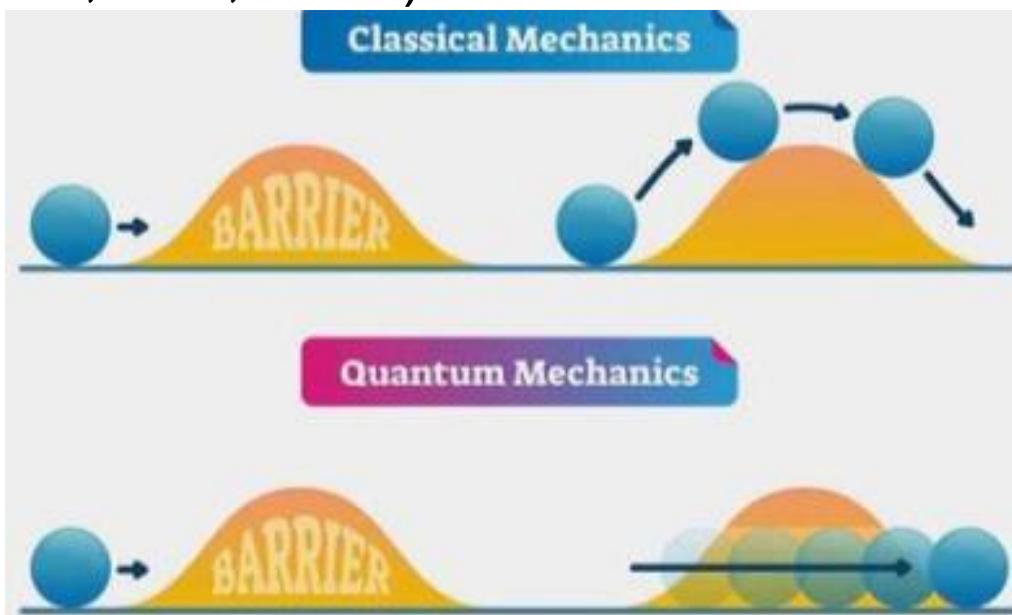
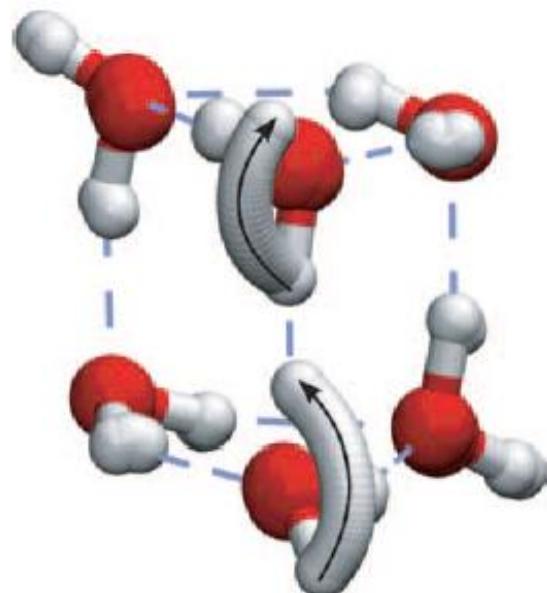
Freezing and Melting of Water (Iwao Ohmine, a former student of Prof. Martin Karplus 2013 Nobel Winner): *Nature* 2002, 416 Aqueous Reactions, 409; *Nature* 2013, 498, 350)

(Extra Info.) Tunneling effect (introduce in Chapter 6)



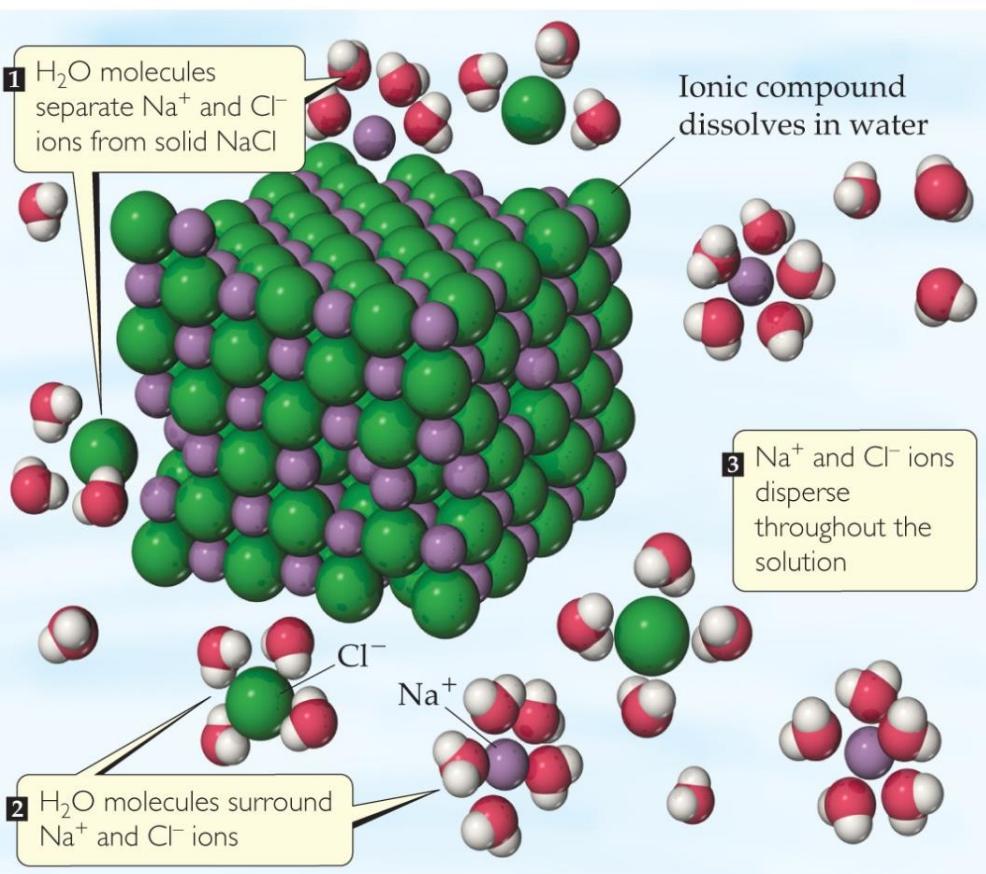
The smallest water cluster with 3-D H-bond networks.

Rotational spectral: Concerted hydrogen-bond breaking by quantum tunneling (*Science* **2016**, *351*, 1310)



Dissociation

Dissociation (解离)

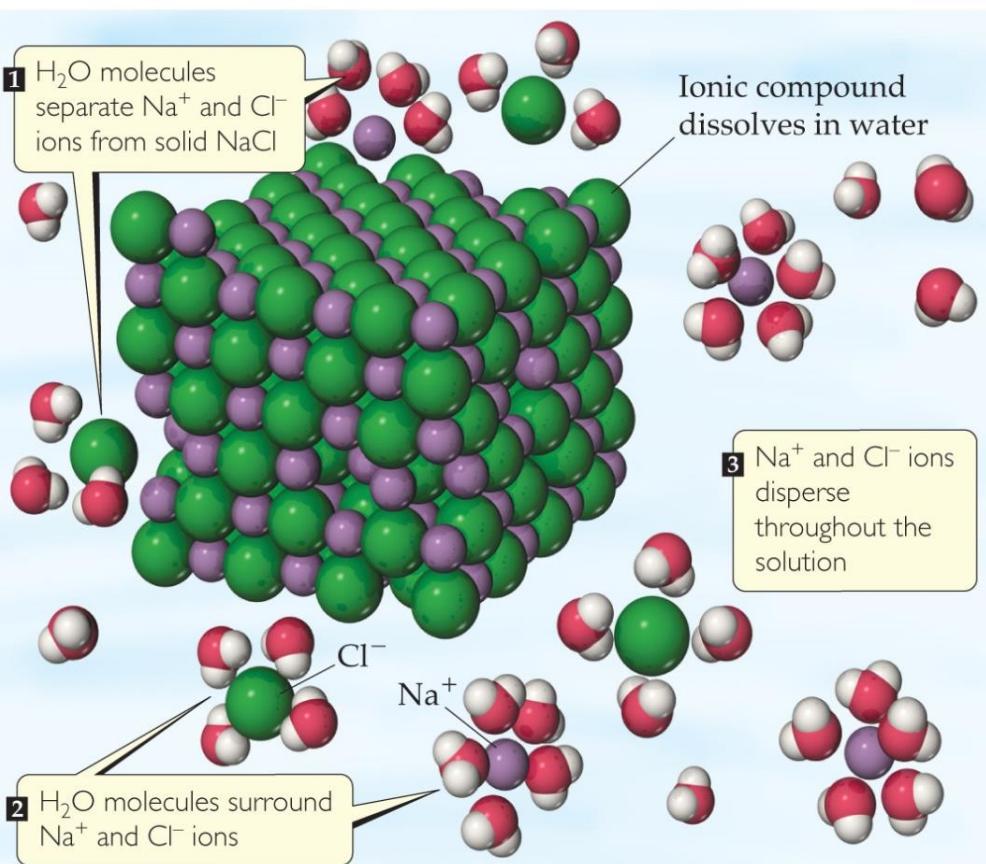


(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

- When an **ionic** substance (e.g. NaCl, sodium chloride) **dissolves** (溶解) in solvent (e.g. water), the solvent pulls the individual ions from the crystal (晶体); the solvent then **solvates these ions (Na^{+(aq)} and Cl^{-(aq)})**.

- This process is called **dissociation** (解离): Aqueous Reactions dissolve & dissociate.

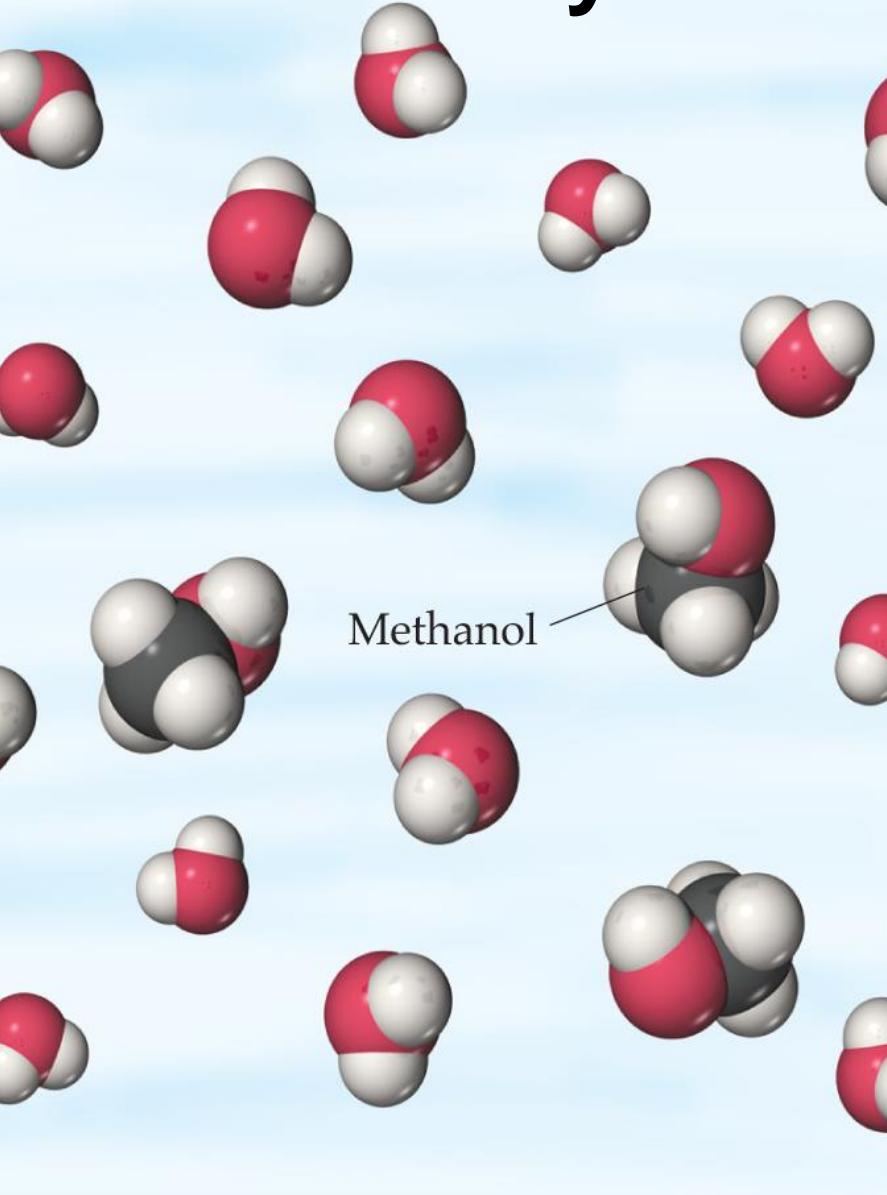
Electrolytes and Nonelectrolytes



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

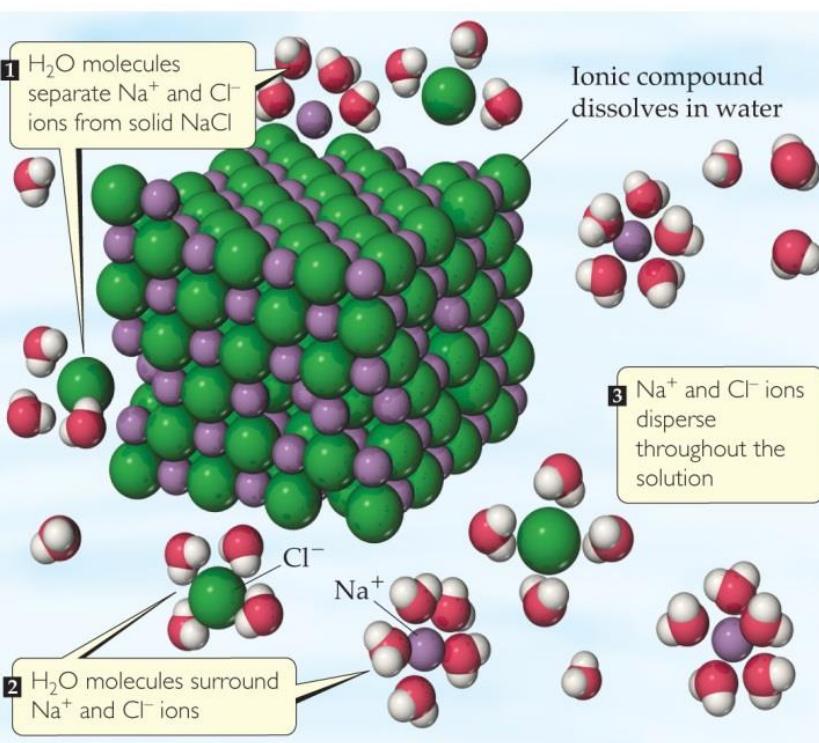
- An **electrolyte** (电解质) is a substance that **dissociates into ions** (e.g. Na⁺ and Cl⁻ for NaCl) when it **dissolves** in water.

Electrolytes and Nonelectrolytes

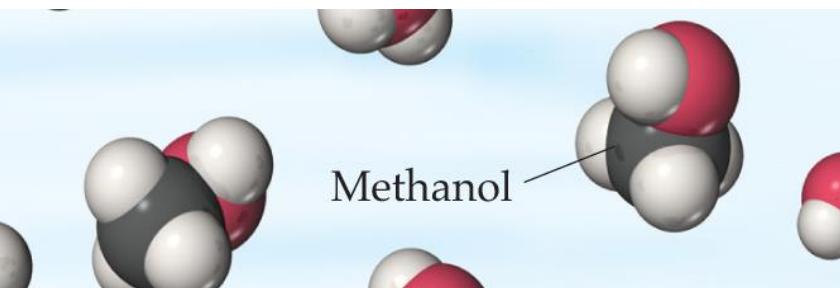


(b) Molecular substances like methanol, CH_3OH , dissolve without forming ions

- A **nonelectrolyte** (非电解质) may **dissolve** in water, but it does **NOT dissociate into ions** (e.g. CH_3OH).



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve



Soluble (可溶的) ionic compounds (metal cations + nonmetal anions) tend to be **electrolytes**.

Molecular compounds (mostly **nonmetals**) tend to be **nonelectrolytes**, **except for acids (e.g. HCl) and bases**.

Electrolytes: Conductivity (导电性)



Pure water,
 $\text{H}_2\text{O}(l)$
does not conduct electricity



Sucrose solution,
 $\text{C}_{12}\text{H}_{22}\text{O}_{11}(aq)$
Nonelectrolyte
does not conduct electricity



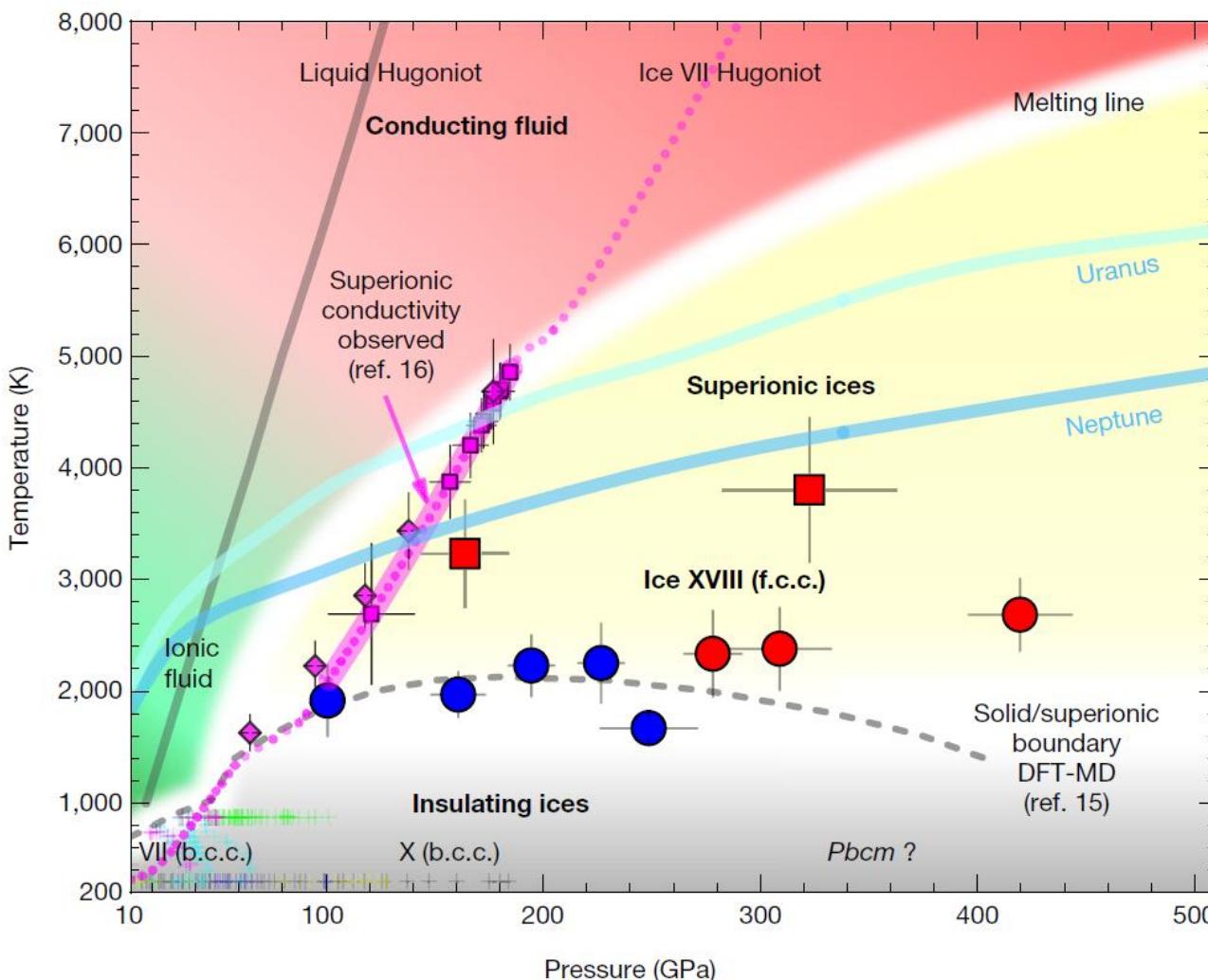
Sodium chloride solution,
 $\text{NaCl}(aq)$
Electrolyte
conducts electricity

- A **strong electrolyte** dissociates (nearly) **completely** into ions when it dissolves in water → a **good conductor**.
- A **weak electrolyte** only dissociates **partially** when it dissolves in water → a **poor conductor**.

(Extra Info.)

Nanosecond X-ray diffraction of shock-compressed superionic water ice

Marius Millot^{1,3*}, Federica Coppari^{1,3*}, J. Ryan Rygg^{1,2}, Antonio Correa Barrios¹, Sébastien Hamel¹, Damian C. Swift¹ & Jon H. Eggert¹



Ice XVIII:

Superionic ice
phase at 100-400
GPa & 2000-3000
K
Crystalline lattice
of oxygen & liquid-
like protons

(Nature 2019
569, 251)
Aqueous
Reactions

Strong Electrolytes

	Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
Ionic	All	None	None
Molecular	Strong acids (see Table 4.2)	Weak acids, weak bases	All other compounds

- **Soluble ionic salts**
- Strong acids
- Strong bases

Ionic salts are strong electrolytes if the dissolved part completely dissociates in water.



Strong Acids & Bases

TABLE 4.2 • Common Strong Acids and Bases

Strong Acids

Hydrochloric, HCl
Hydrobromic, HBr
Hydroiodic, HI
Chloric, HClO_3
Perchloric, HClO_4
Nitric, HNO_3
Sulfuric, H_2SO_4

Strong Bases

Group 1A metal hydroxides [LiOH, NaOH, KOH, RbOH, CsOH]
Heavy group 2A metal hydroxides [Ca(OH)₂, Sr(OH)₂, Ba(OH)₂]

What dissolved species are present in a solution of

- a. KCN,
- b. NaClO₄?

a.

- A. H₂O(l)
- B. K⁺(aq) and H₂O(l)
- C. CN⁻(aq)
- D. K⁺(aq) and CN⁻(aq)

b.

- A. H₂O(l)
- B. Na⁺(aq) and H₂O(l)
- C. ClO₄⁻(aq)
- D. Na⁺(aq) and ClO₄⁻(aq)

钠离子 Na⁺ sodium ion

钾离子 K⁺ potassium ion

高氯酸根离子 ClO₄⁻ perchlorate ion

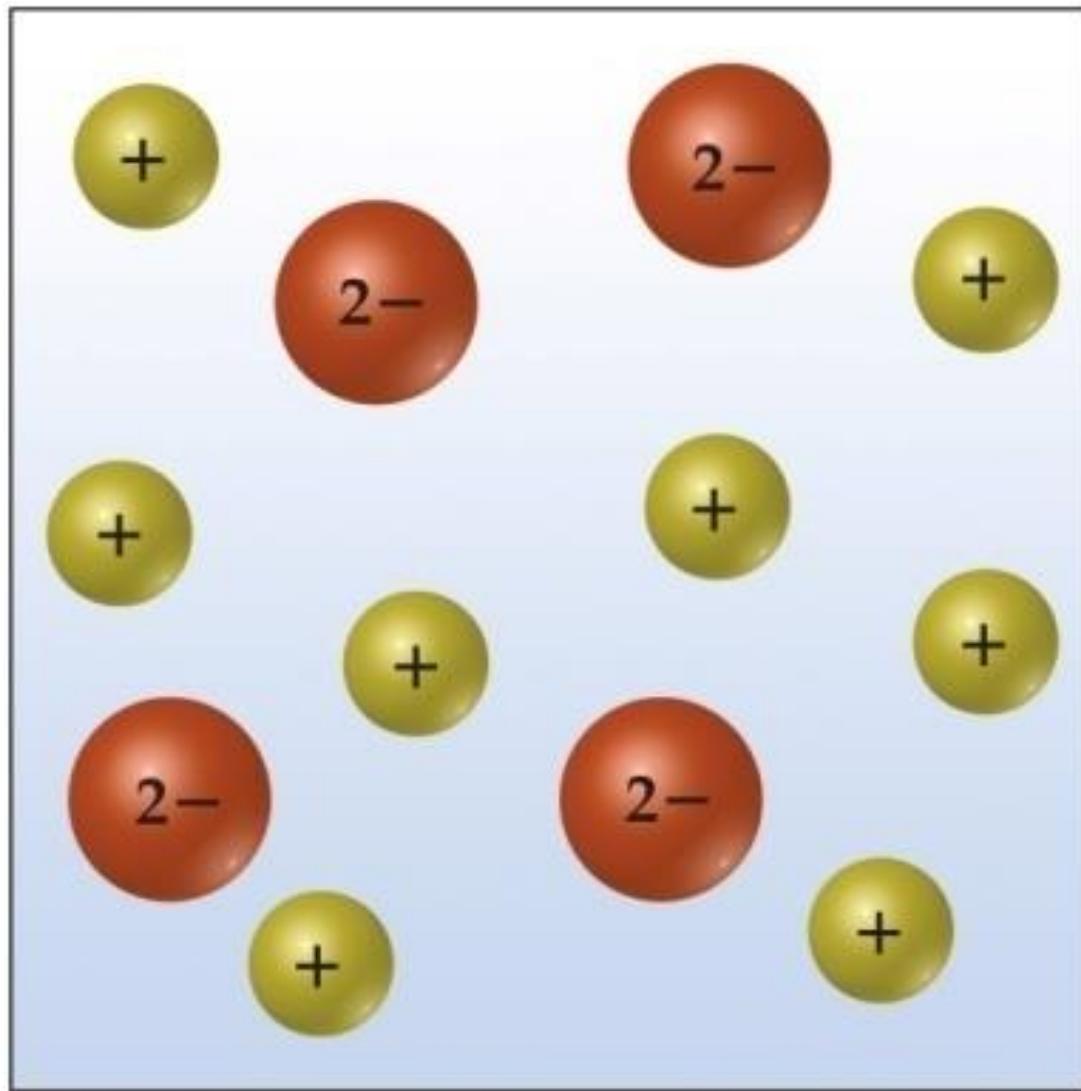
氰离子 CN⁻ cyanide ion

Which solute will cause the lightbulb in Figure 4.2 to glow most brightly, CH_3OH , NaOH , or CH_3COOH ?

- A. $\text{CH}_3\text{OH}(\text{aq})$
- B. $\text{NaOH}(\text{aq})$
- C. $\text{CH}_3\text{COOH}(\text{aq})$
- D. Cannot determine from Figure 4.2

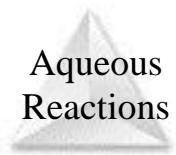
醋酸-acetic acid

The below diagram represents an aqueous solution of either MgCl_2 , KCl , or K_2SO_4 . Which solution does the drawing best represent?



Classify these dissolved substances as a strong, weak, or nonelectrolyte: CaCl_2 , HNO_3 , $\text{C}_2\text{H}_5\text{OH}$ (ethanol), HCOOH (formic acid), KOH .

HCOOH formic acid (甲酸, 蚁酸)



Precipitation

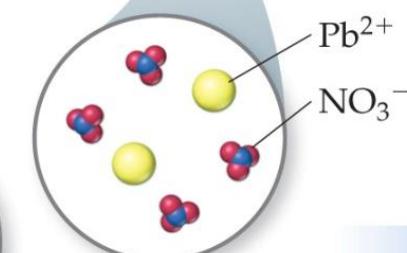
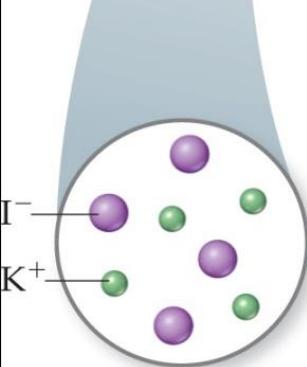
Precipitation (沉淀反应) Reactions

When one mixes ions that form **insoluble** (不可溶的) compounds (could be predicted by the solubility guidelines), a **precipitate** (沉淀物) in a **solid** form is formed.

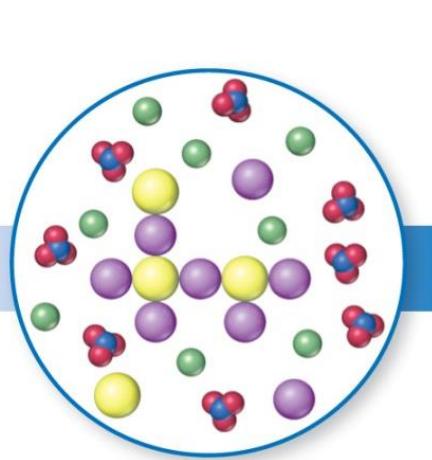
Interactions between the cations and anions are **too strong** to be separated (dissolved).



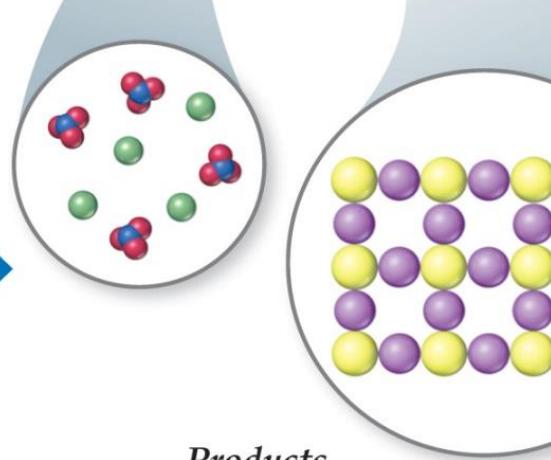
Which ions remain in solution after PbI_2 precipitation is complete?



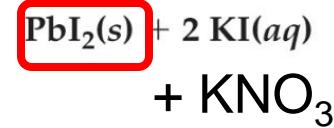
Reactants



$\text{Pb}^{2+}(aq)$ and $\text{I}^-(aq)$ combine
to form precipitate



Products



Solubility guidelines (Nitrate, acetate, chloride, bromide, iodide, sulfate, sulfide, carbonate, phosphate, hydroxide)

TABLE 4.1 • Solubility Guidelines for Common Ionic Compounds in Water

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	CH_3COO^-	None
	Cl^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	Br^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	I^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+} , Ba^{2+} , Hg_2^{2+} , and Pb^{2+}
Insoluble Ionic Compounds		Important Exceptions
Compounds containing	S^{2-}	Compounds of NH_4^+ , the alkali metal cations, Ca^{2+} , Sr^{2+} , and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of NH_4^+ , the alkali metal cations, Ca^{2+} , Sr^{2+} , and Ba^{2+}

I^- 碘离子 iodide ion; I 碘 iodine;

Br^- 溴离子 bromide ion; Br 溴 bromine

Cl^- 氯离子 chloride ion; Cl 氯 chlorine

F^- 氟离子 fluoride ion; F 氟 fluorine

Metathesis (Exchange) Reactions

复分解(交换)反应

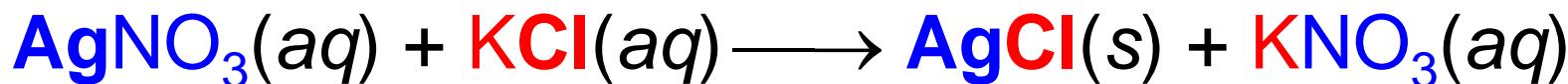
- Metathesis: from a Greek word that means “to transpose (调换).”



Metathesis (Exchange) Reactions

复分解(交换)反应

- Metathesis: from a Greek word that means “to transpose (调换).”
- Appears as though the ions in the reactant compounds **exchange** or transpose **ions**:



Solution Chemistry

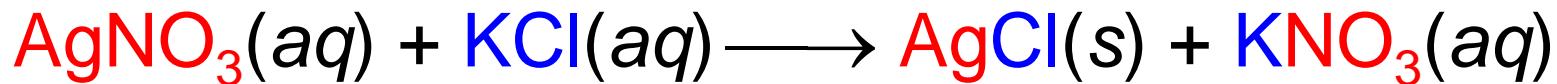
- It is helpful to pay attention to *exactly* what species are present in a reaction mixture (i.e., solid, liquid, gas, aqueous solution).



- If we like to understand **reactivity**, we must be aware of just **what** is **changing** during the course of a reaction.

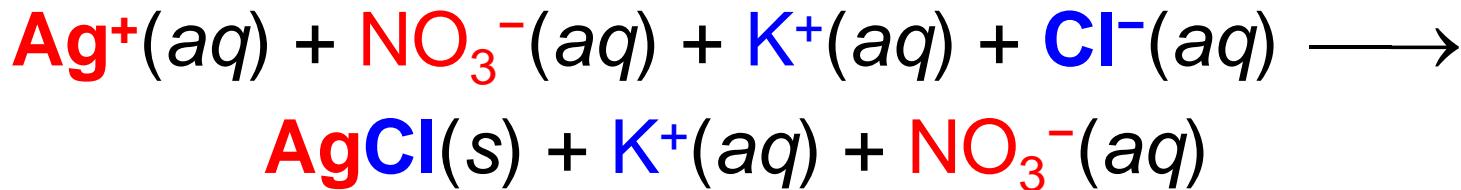
Molecular Equation

The **molecular equation** lists the reactants and products in their **molecular form**:



Ionic Equation

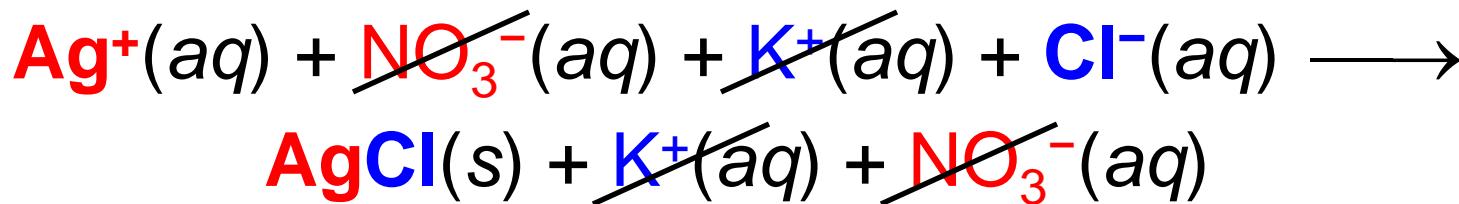
- In the **ionic equation**, **all strong electrolytes** (strong acids, strong bases, and soluble ionic salts) are **dissociated into their ions** (e.g. $\text{Na}^+(\text{aq})$ and $\text{Cl}^-(\text{aq})$).
- This **more accurately reflects the species** that are found in the reaction mixture:



- Ions which do not involve the reaction are called **spectator ions** (they were **deleted** from the **net ionic equation**). e.g. $\text{NO}_3^-(\text{aq})$ & $\text{K}^+(\text{aq})$.

Net Ionic Equation (净离子方程式)

- To form the **net** ionic equation, **delete anything (spectator ions)** that does **not change** from both the left and right sides of the equation:



- The only things left in the equation are ions that change (i.e., react) during the course of the reaction:



Classify these ionic compounds as soluble or insoluble in water: (a) sodium carbonate, Na_2CO_3 , (b) lead sulfate, PbSO_4 .

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	CH_3COO^-	None
	Cl^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	Br^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	I^-	Compounds of Ag^+ , Hg_2^{2+} , and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+} , Ba^{2+} , Hg_2^{2+} , and Pb^{2+}
Insoluble Ionic Compounds		Important Exceptions
Compounds containing	S^{2-}	Compounds of NH_4^+ , the alkali metal cations, Ca^{2+} , Sr^{2+} , and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
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	OH^-	Compounds of NH_4^+ , the alkali metal cations, Ca^{2+} , Sr^{2+} , and Ba^{2+}

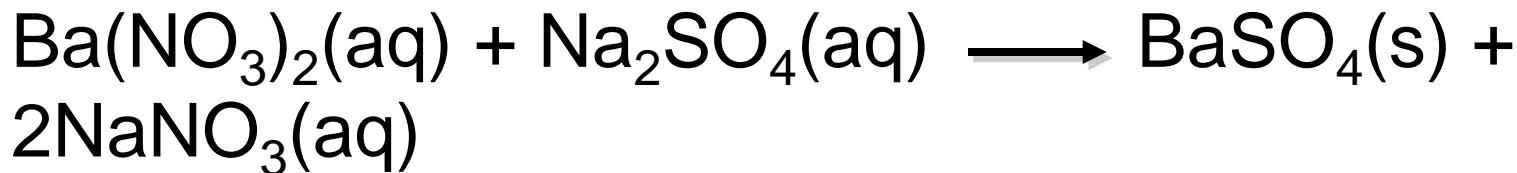
When $\text{Fe}(\text{NO}_3)_2$ dissolves in water, the particles in solution are

- a. Fe^+ and $(\text{NO}_3)_2^-$.
- b. Fe^{2+} and 2NO_3^- .
- c. Fe and 2NO_3^- .
- d. Fe and N_2 and 3O_2 .

Which compound below is NOT soluble in water?

- a. NaBr
- b. KNO_3
- c. MgSO_4
- d. ZnS

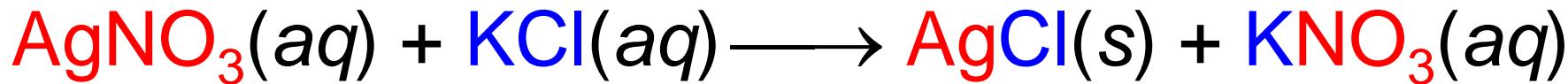
Which ions, if any, are spectator ions in the reaction?



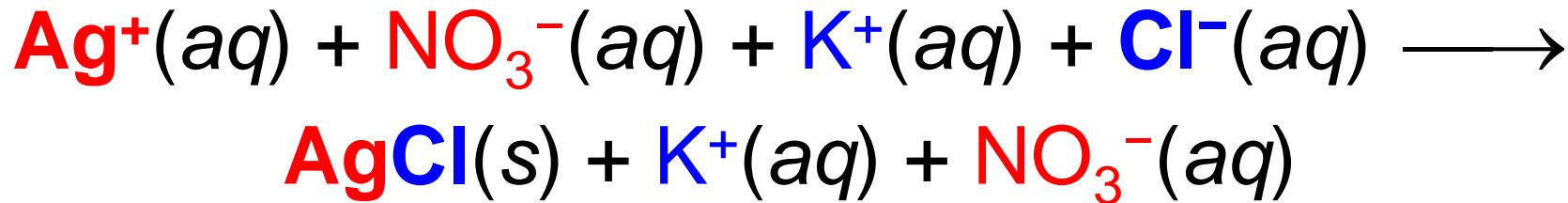
- A. $\text{Ba}^{2+}(\text{aq})$ and $\text{NO}_3^-(\text{aq})$
- B. $\text{NO}_3^-(\text{aq})$ and $\text{SO}_4^{2-}(\text{aq})$
- C. $\text{Na}^+(\text{aq})$ and $\text{NO}_3^-(\text{aq})$
- D. No spectator ions are involved

Writing Net Ionic Equations

1. Write a balanced molecular equation.



2. Express dissociation of all strong electrolytes into ions (e.g. $\text{K}^+(\text{aq})$, $\text{Cl}^-(\text{aq})$).

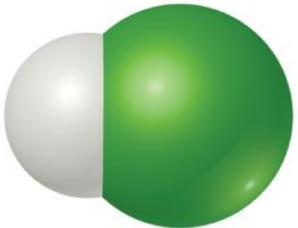


3. Delete spectator ions from **both the sides** of the equation.

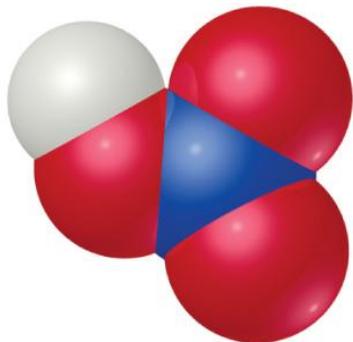


Acids & Bases

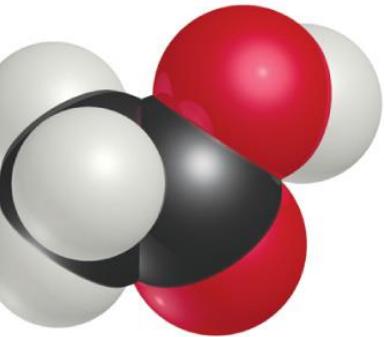
**(learn more from
Chapters 16-17)**



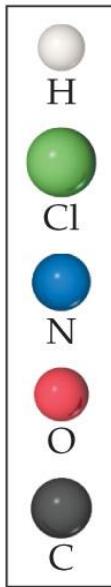
Hydrochloric acid, HCl



Nitric acid, HNO₃



Acetic acid, CH₃COOH



Acids

- Arrhenius defined acids as substances that **increase the concentration of H⁺(aq)** when it **dissolves** in water (**Arrhenius acid-base theory** 阿伦尼乌斯酸碱理论).

- Both Brønsted and Lowry defined them as **proton donors** (质子供体) (**Brønsted-Lowry acid-base theory** 布朗斯特-劳里酸碱理论).

H⁺: proton ion; H: hydrogen atom
H⁻: hydride ion

Extra Info.: more general definition by Lewis acid-base theory (in terms of “electron”, Chapter 17).

Seven **strong acids** (**complete ionization** to give $\text{H}^+(\text{aq})$, strong electrolyte):

Hydrochloric Acid (HCl)

Hydrobromic Acid (HBr)

Hydroiodic Acid (HI)

Nitric Acid (HNO_3)

Sulfuric Acid (H_2SO_4)

Chloric Acid (HClO_3) (氯酸)

Perchloric Acid (HClO_4) (高氯酸)



Weak acids (**partial ionization** to give $\text{H}^+(\text{aq})$): e.g.

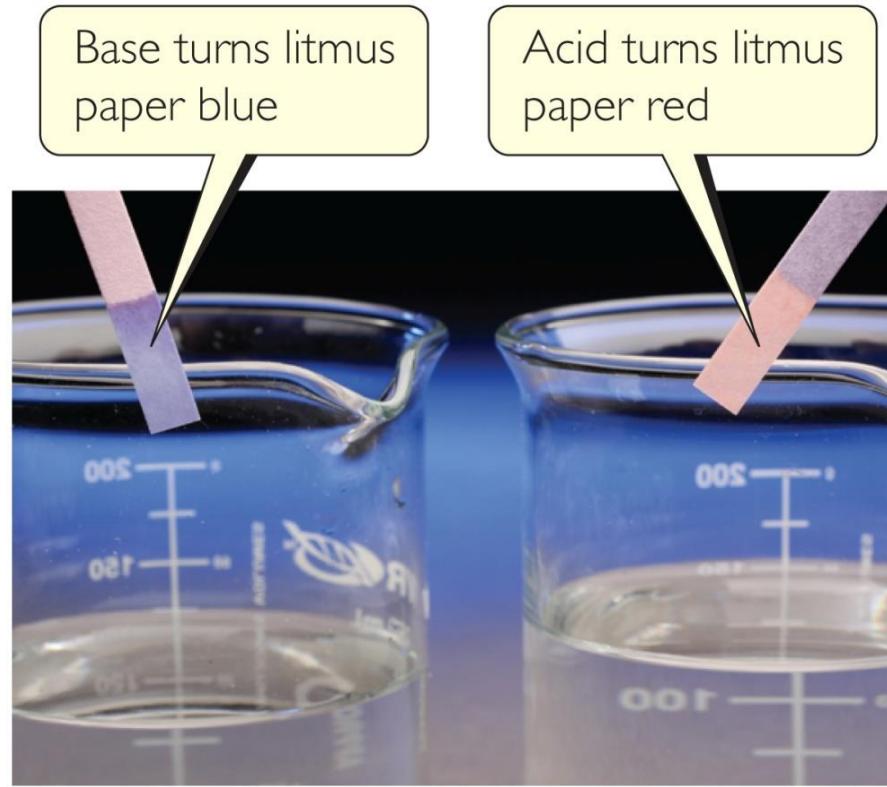
Acetic acid ($\text{CH}_3\text{CO}_2\text{H}$).



Monoprotic acid (HA) & Diprotic acid (H_2A)

Bases

- Arrhenius defined bases as substances that **increase the concentration of $\text{OH}^-(\text{aq})$** when it dissolves in water.
- Brønsted and Lowry defined them as **proton acceptors** (质子受体).



Litmus paper (石蕊试纸)

The **strong bases** are the ***soluble*** metal hydroxide (**MOH**) with **complete ionization (dissociation)**:

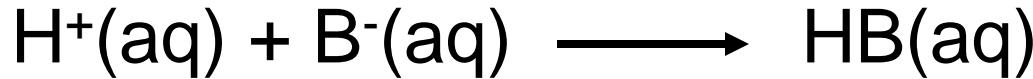
Metals (M):

Alkali metals (碱金属)

Calcium (钙)

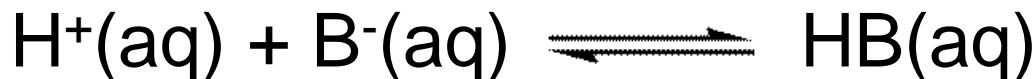
Strontium (锶)

Barium (钡)



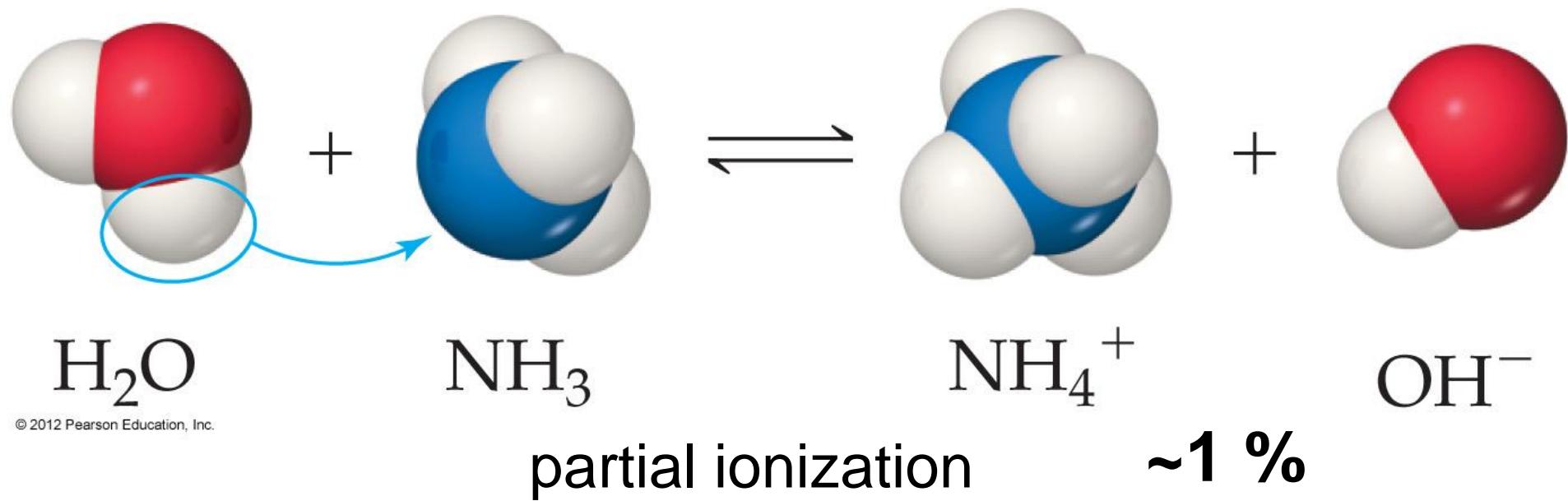
Weak bases:

e.g. NH_3



Acid-Base Reactions

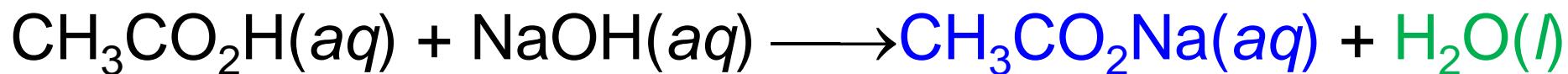
In an acid-base reaction, the acid donates a proton (H^+) to the base.



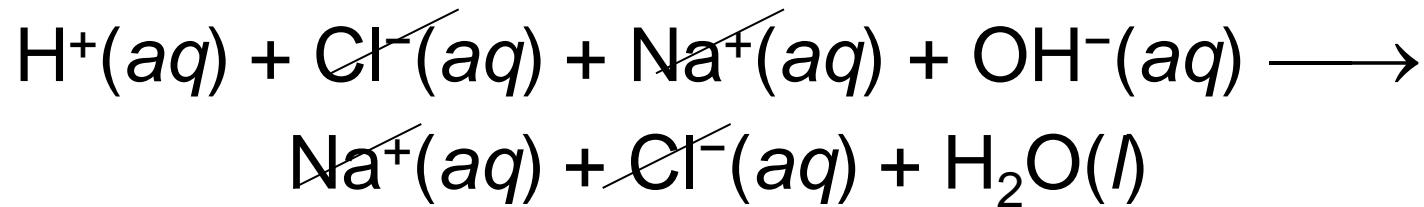
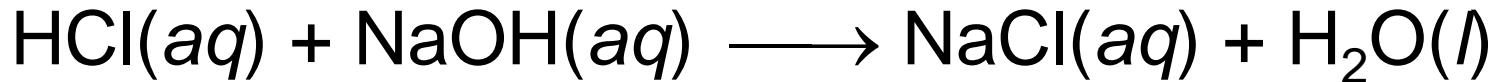
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Neutralization Reactions (中和反应)

Generally, when solutions of an acid and a base are combined, the products are a **salt** and **water**:

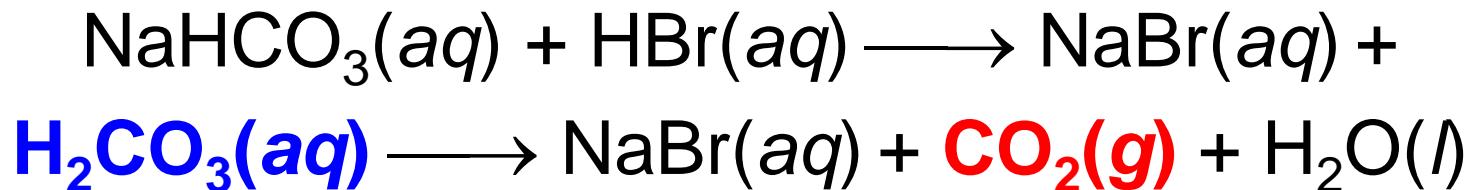


When a strong acid reacts with a strong base, the net ionic equation is



Gas-Forming Reactions

- When a **carbonate** (CO_3^{2-}) or **hydrogen carbonate** (**bicarbonate**, HCO_3^-) reacts with an acid, the products are a salt, **gaseous carbon dioxide**, and water.



Calcium Carbonate 碳酸钙

Aqueous
Reactions

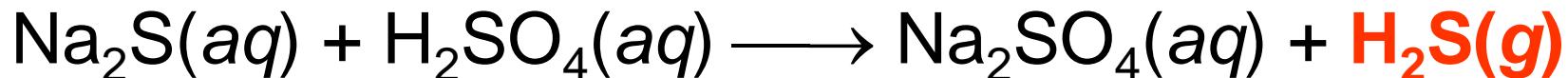
Sodium hydrogen carbonate 碳酸氢钠

2. When a **sulfite** (SO_3^{2-}) reacts with an acid, the products are a salt, **gaseous sulfur dioxide**, and water:



Strontium sulfite 亚硫酸锶

3. When a **sulfide** (S^{2-}) reacts with an acid, the products are a salt and **bad-smell** gas (H_2S):



Sulfuric acid 硫酸

Hydrogen sulfide 硫化氢

Antacids (抗酸剂)



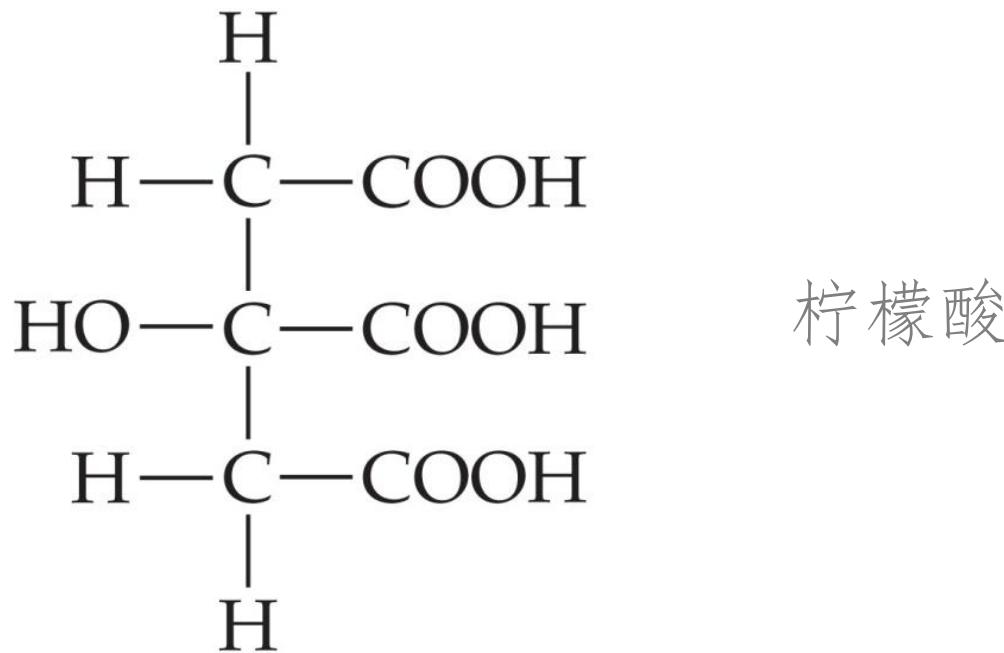
Commercial Name

Alka-Seltzer®
Amphojel®
Di-Gel®
Milk of Magnesia
Maalox®
Mylanta®
Rolaids®
Tums®

Acid-Neutralizing Agents

NaHCO_3
 Al(OH)_3
 Mg(OH)_2 and CaCO_3
 Mg(OH)_2
 Mg(OH)_2 and Al(OH)_3
 Mg(OH)_2 and Al(OH)_3
 $\text{NaAl(OH)}_2\text{CO}_3$
 CaCO_3

The structural formula of citric acid, a main component of citrus fruits, is



How many $\text{H}^+(\text{aq})$ can be generated by each citric acid molecule dissolved in water?

- A. 4
- B. 1
- C. 2
- D. 3

Why isn't Al(OH)₃ classified as a strong base?

- A. Al(OH)₃ is not basic in water.
- B. Al(OH)₃ is insoluble in water.
- C. Al(OH)₃ is a strong acid in water, not basic.
- D. Al(OH)₃ is a weak acid in water, not basic.

Aluminium hydroxide (氢氧化铝)

When an acid reacts with a base, the result is

- a. cancellation.
- b. elimination.
- c. neutralization.
- d. adduct formation.

Which compound below is NOT a strong acid?

- a. $\text{CH}_3\text{CO}_2\text{H}$
- b. H_2SO_4
- c. HNO_3
- d. HBr

By analogy to examples given in the text, predict what gas forms when $\text{Na}_2\text{SO}_3(s)$ reacts with $\text{HCl}(aq)$.

- A. $\text{SO}_2(g)$
- B. $\text{H}_2(g)$
- C. $\text{CO}_2(g)$
- D. $\text{H}_2\text{S}(g)$

sodium sulfite 亚硫酸钠
Sodium sulfide 硫化钠
Sodium sulfate 硫酸钠
Sulfur dioxide 二氧化硫
Sulfite ion 亚硫酸根离子
Bisulfite 亚硫酸氢根离子
Sulfate ion 硫酸根

Oxidation- Reduction Reactions (learn more from Chapter 20)



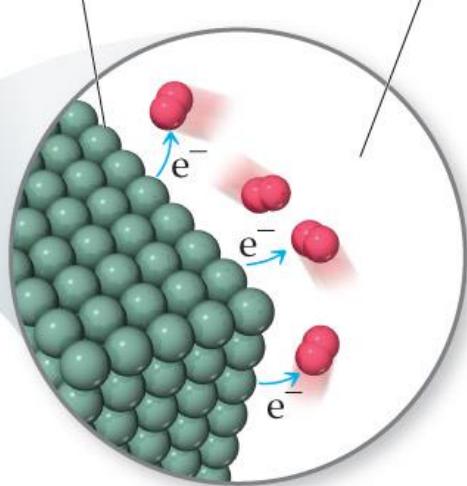
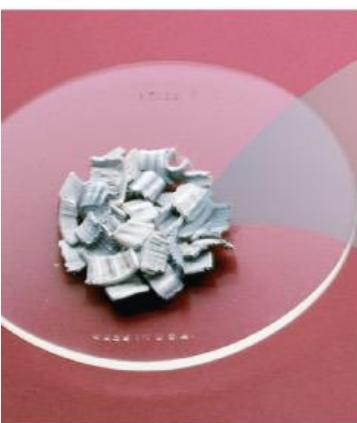
Oxidation-Reduction (Redox) Reactions

(氧化-还原反应)

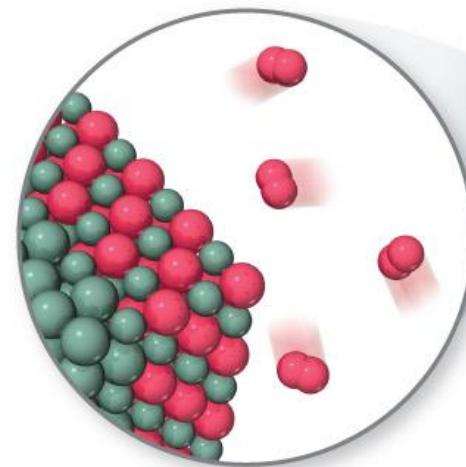
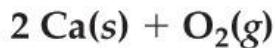
Ca(s) is oxidized
(loses electrons)

O₂(g) is reduced
(gains electrons)

Ca²⁺ and O²⁻ ions
combine to form CaO(s)



Reactants



Products

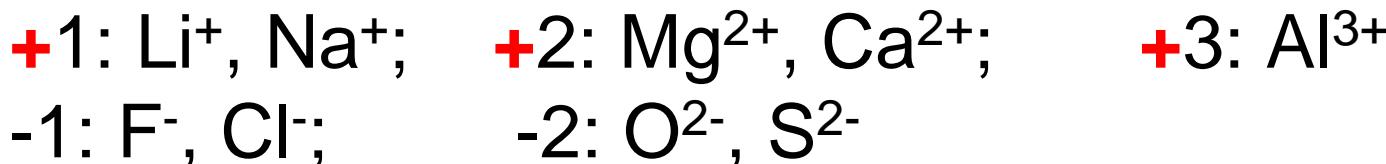


- An **oxidation** occurs when an atom, molecule or ion (e.g. metals) **loses electron(s)**.
- A **reduction** occurs when an atom, molecule or ion (the right side of periodic table) **gains electron(s)**.
- One **CANNOT occur without the other**.

Oxidation Numbers (氧化数)

For an oxidation-reduction reaction, we assign an **oxidation number** (oxidation state) to **each element** in a neutral compound or charged species.

- Atoms (i.e. neutral) in their **elemental form** have an oxidation number of **0**.
e.g. He, Li, H₂, O₂, N₂, P₄
- The oxidation number of a **monatomic ion** is the **same** as its **charge**. e.g.



- **Nonmetals** (非金属) tend to have **negative** oxidation numbers, although **some are positive** in certain compounds or ions. e.g.

Oxygen usually has an oxidation number of **-2** (e.g. H_2O) except **peroxide** (过氧化物) compounds: **-1** (H_2O_2) and unusually **+2** for OF_2 (oxygen difluoride, 剧毒气体, 火箭工程液体助燃剂).

Hydrogen:

- 1** when bonded to a **metal** (e.g. NaH , sodium hydride).
- +1** when bonded to a **nonmetal** (e.g. H_2O , H_2S).

Fluorine(氟) **always** has an oxidation number of **-1** (e.g. HF) in all compounds: the **highest electronegativity**.

The other halogens(卤素) have an oxidation number of **-1** in most binary compounds, but they can have positive oxidation numbers in oxyanions: e.g.

Cl:

+7: ClO_4^- (perchlorate): $x + 4*(-2) = -1 \rightarrow x = +7$

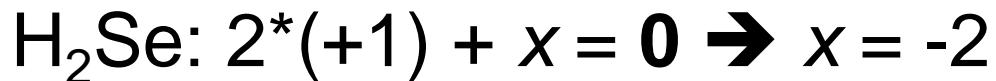
+5: ClO_3^- (chlorate): $x + 3*(-2) = -1 \rightarrow x = +5$

+3: ClO_2^- (chlorite): $x + 2*(-2) = -1 \rightarrow x = +3$

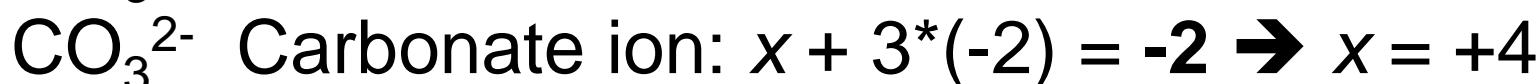
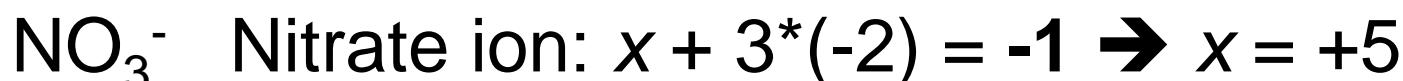
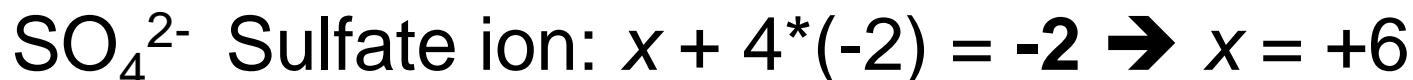
+1: ClO^- (hypochlorite): $x + -2 = -1 \rightarrow x = +1$

-1: HCl : $1 + x = 0 \rightarrow x = -1$

- The **sum** of the oxidation numbers of all atoms in a **neutral compound** is **0**. e.g.



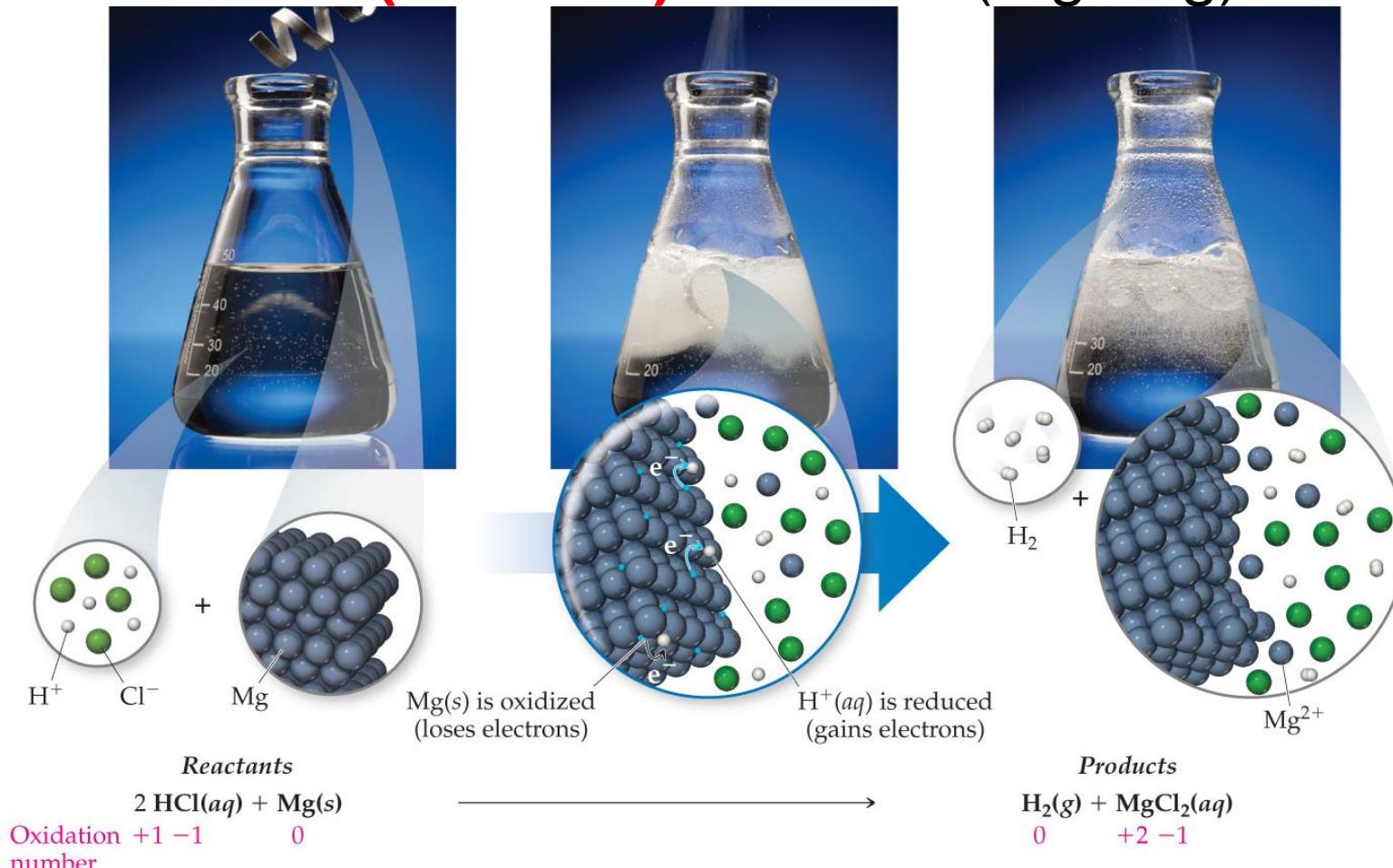
- The **sum** of the oxidation numbers of all atoms in a polyatomic **ion** is the **charge** on the ion.

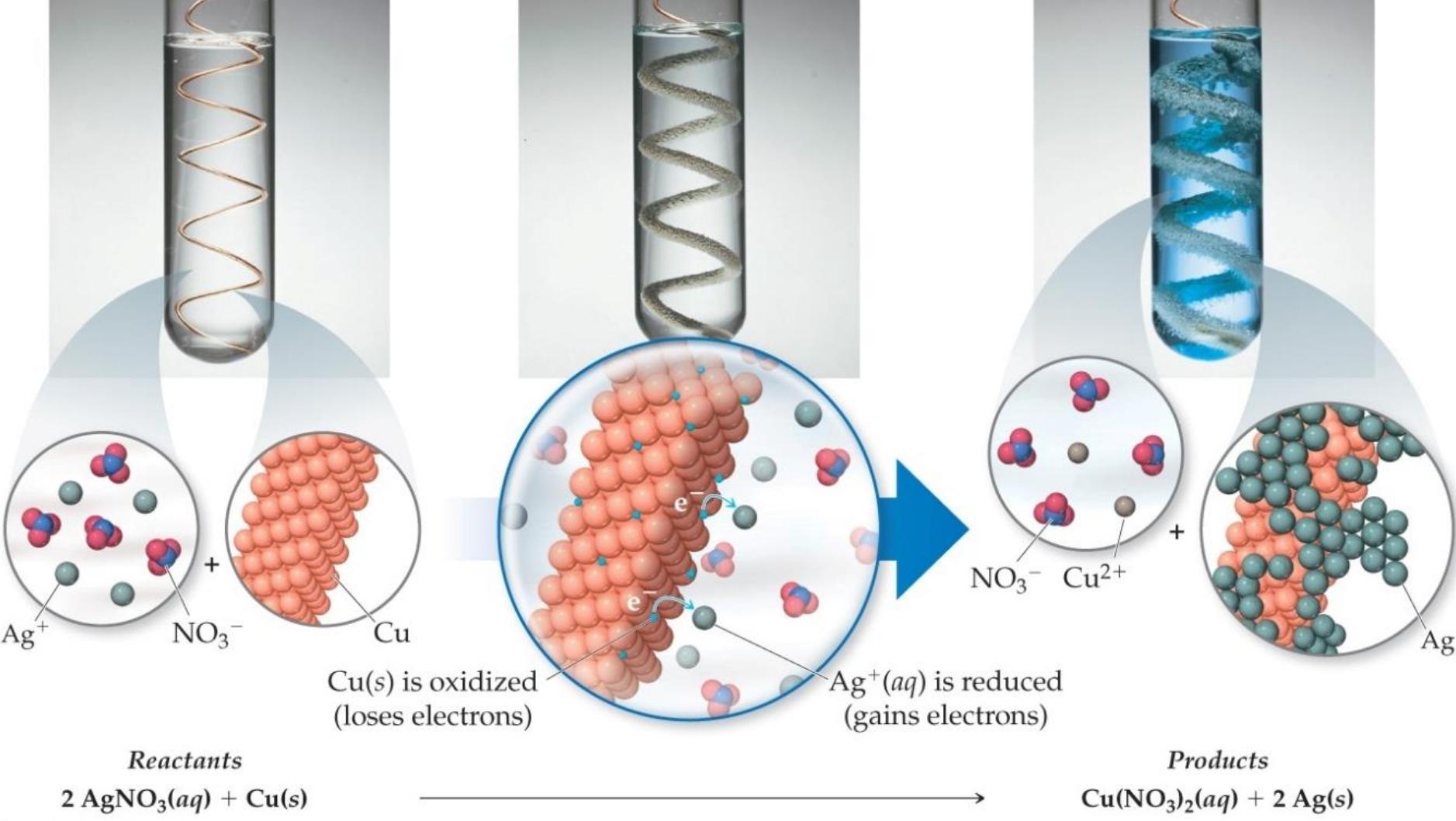


Displacement Reactions (置换反应)



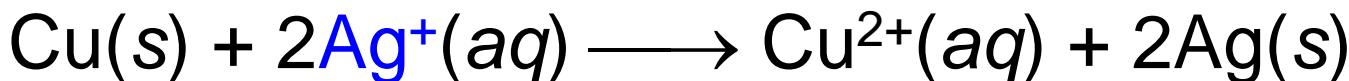
The **cation** (e.g. H^+) in solution is replaced by **oxidation of an (reactive) element** (e.g. Mg).

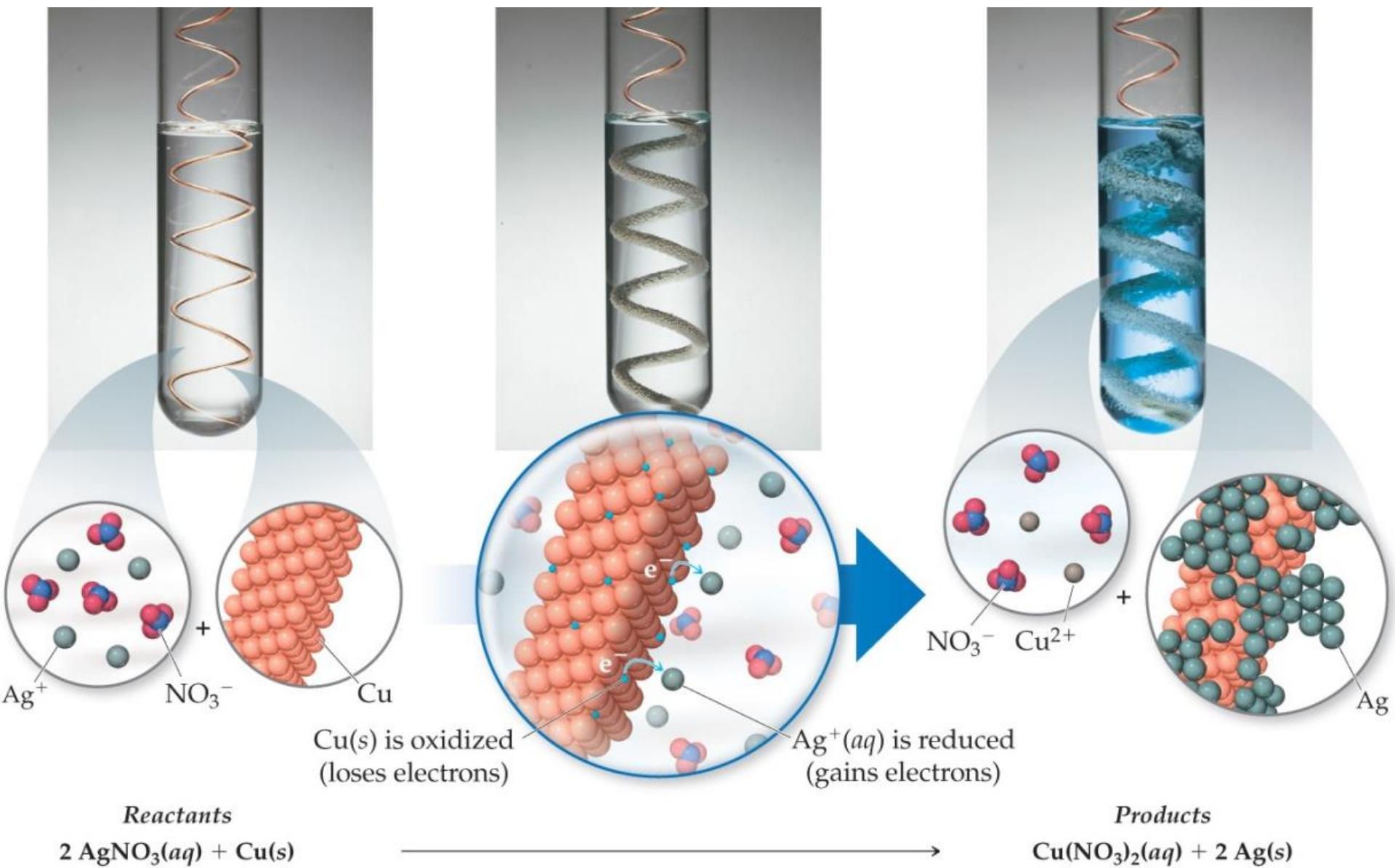




Redox reactions (1) between **metals** and **acids** as well as those (2) between **metals** and **salts**.

e.g. silver ions oxidize copper metal:





The **reverse** (逆) reaction does **NOT** occur:

$$\text{Cu}^{2+}(aq) + 2\text{Ag}(s) \rightarrow \text{Cu}(s) + 2\text{Ag}^+(aq)$$

Activity Series (活性顺序)



Metal	Oxidation Reaction	
Lithium	$Li(s) \rightarrow Li^+(aq) + e^-$	 <p>Ease of oxidation increases</p>
Potassium	$K(s) \rightarrow K^+(aq) + e^-$	
Barium	$Ba(s) \rightarrow Ba^{2+}(aq) + 2e^-$	
Calcium	$Ca(s) \rightarrow Ca^{2+}(aq) + 2e^-$	
Sodium	$Na(s) \rightarrow Na^+(aq) + e^-$	
Magnesium	$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$	
Aluminum	$Al(s) \rightarrow Al^{3+}(aq) + 3e^-$	
Manganese	$Mn(s) \rightarrow Mn^{2+}(aq) + 2e^-$	
Zinc	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$	
Chromium	$Cr(s) \rightarrow Cr^{3+}(aq) + 3e^-$	
Iron	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$	
Cobalt	$Co(s) \rightarrow Co^{2+}(aq) + 2e^-$	
Nickel	$Ni(s) \rightarrow Ni^{2+}(aq) + 2e^-$	
Tin	$Sn(s) \rightarrow Sn^{2+}(aq) + 2e^-$	
Lead	$Pb(s) \rightarrow Pb^{2+}(aq) + 2e^-$	
Hydrogen	$H_2(g) \rightarrow 2 H^+(aq) + 2e^-$	
Copper	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$	
Silver	$Ag(s) \rightarrow Ag^+(aq) + e^-$	
Mercury	$Hg(l) \rightarrow Hg^{2+}(aq) + 2e^-$	
Platinum	$Pt(s) \rightarrow Pt^{2+}(aq) + 2e^-$	
Gold	$Au(s) \rightarrow Au^{3+}(aq) + 3e^-$	
Active metals		<p>Any active metal A can be oxidized by the ions of elements B below the metal A in this list.</p> 
Noble metals		<p>? Essay: New energy application</p> <p>Aqueous Reactions</p>

Extra Info./References:

The **reactivity series**: list of metals (sometimes with H & C added as baseline) **arranged by the ability to reduce** other chemicals in nonspecific way.

Reactivity series:

K, *Na, *Ca, Mg, Al, Zn, Fe, Sn, Pb, Cu, Hg, Ag, Au
← **increase in reactivity**

*: the position of Ca & Na are **different** in **electrochemical series**, Ca is more electropositive than Na, but not for the reactivity series.

This is **in contract with the electrochemical series**:

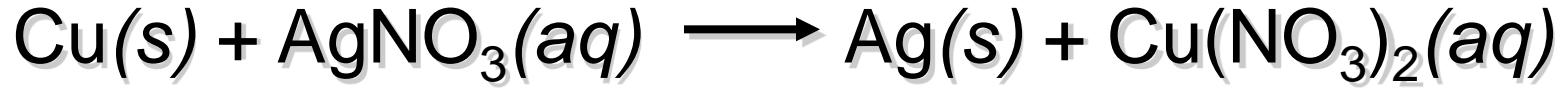
List of reducing agents arranged by the way of negative potential in an electrochemical cell.

Extra Info./References:

- Na being above Ca in the Reactivity Series; Ca being above Na in the Electrochemical Series.
- Metals with lower valencies tend to be higher in the Reactivity Series because they only need to lose one electron to form a stable noble gas structure with a full outer electron shell.
- The reason for this being that metals with higher valencies tend to be higher in the Electrochemical Series, because more electrons are needed to produce each atom.

http://chemwiki.ucdavis.edu/Reference/Reference_Tables/Electrochemistry_Tables/P3%3A_Activity_Series_of_Metals

http://en.wikipedia.org/wiki/Reactivity_series



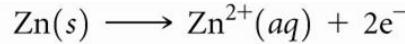
Copper

Silver





Zinc



Chromium



Iron



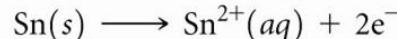
Cobalt



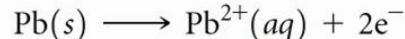
Nickel



Tin



Lead



Hydrogen



Copper

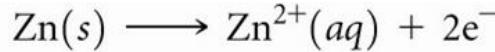


Silver

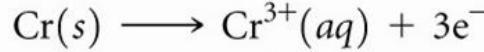




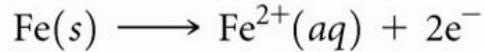
Zinc



Chromium



Iron



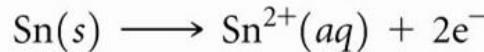
Cobalt



Nickel



Tin

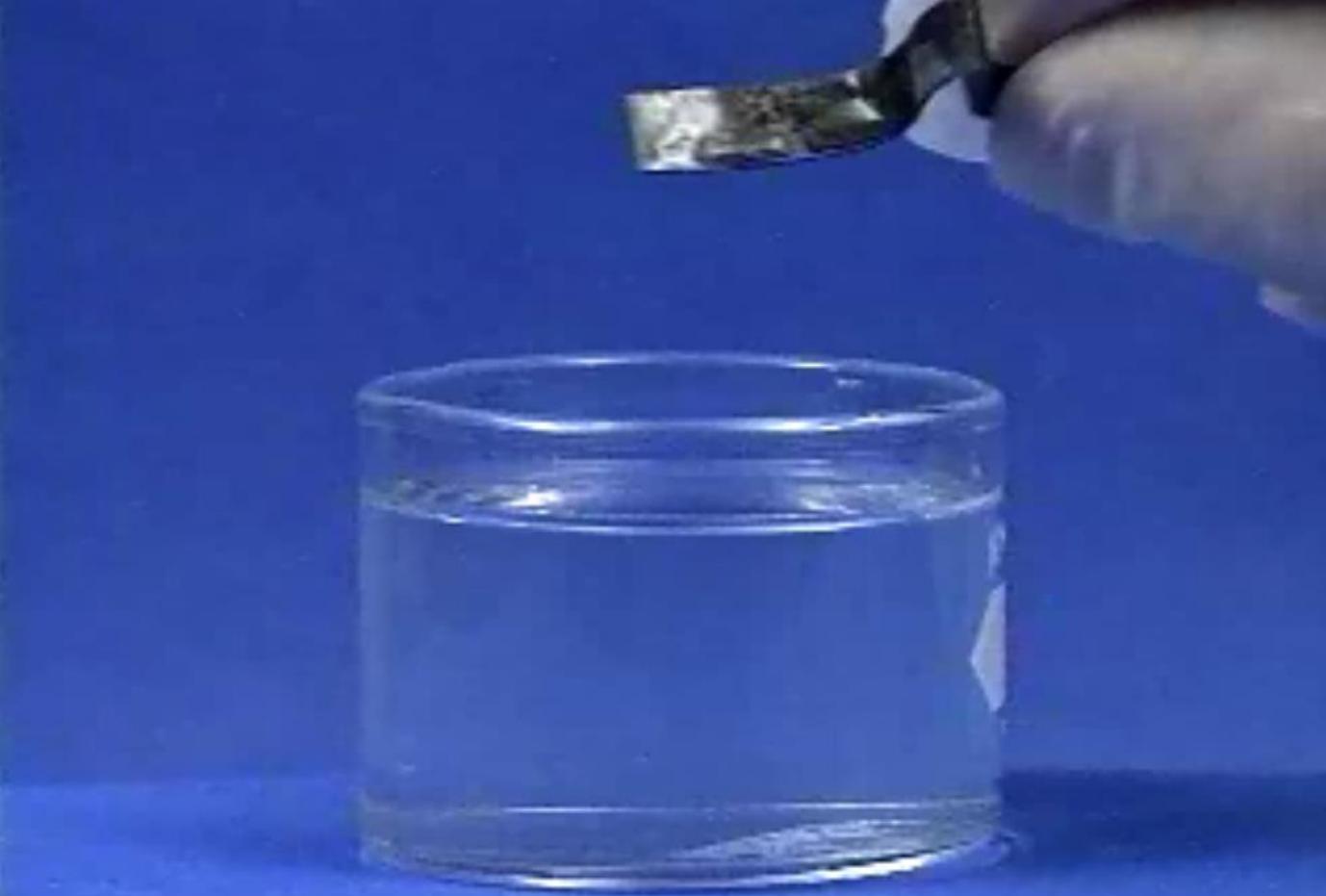


Lead

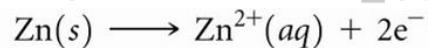


Lead (鉛)

Aqueous
Reactions



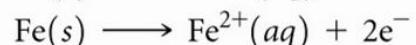
Zinc



Chromium



Iron



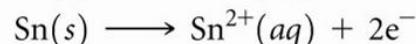
Cobalt



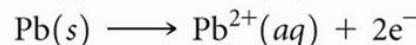
Nickel



Tin



Lead

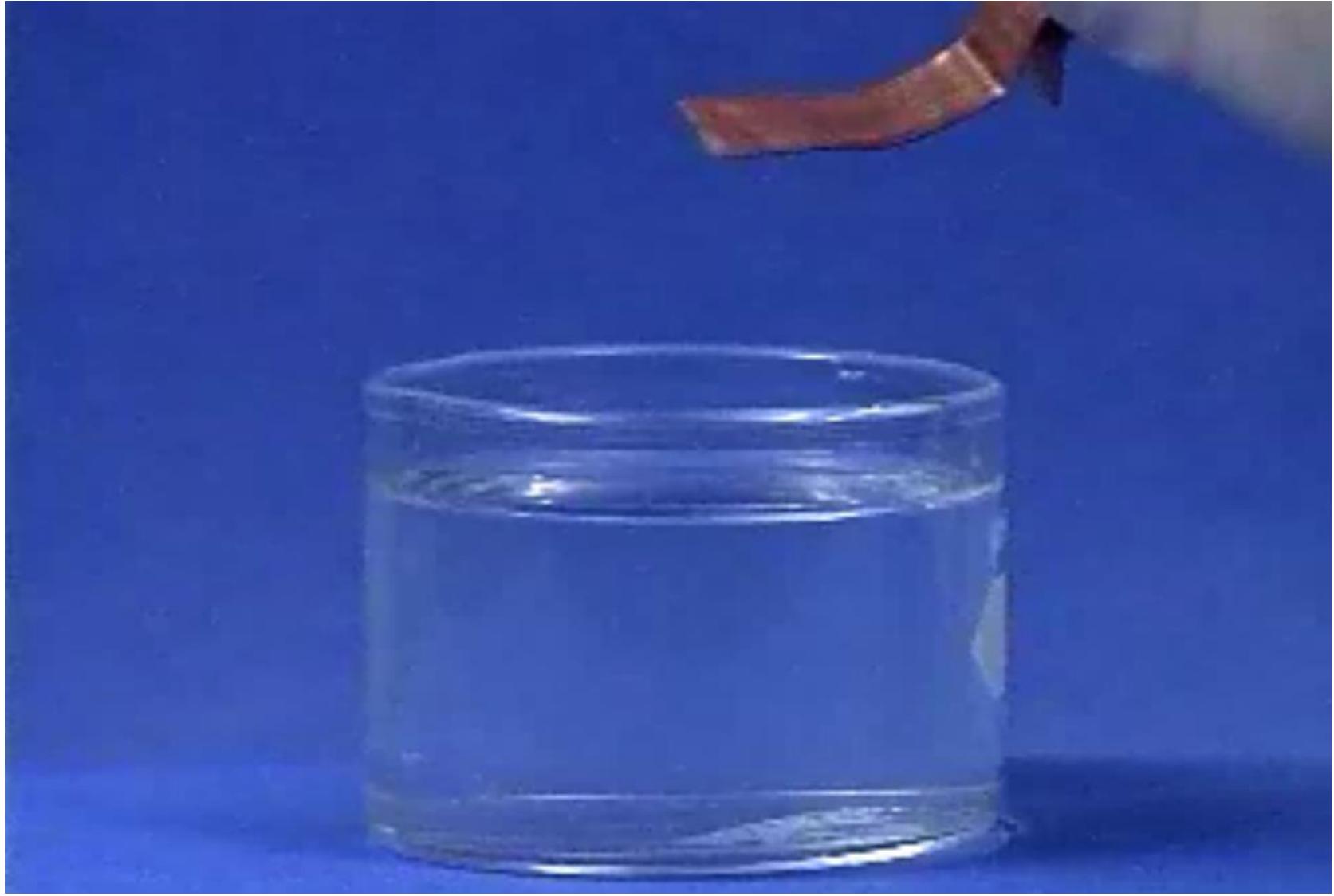


Hydrogen



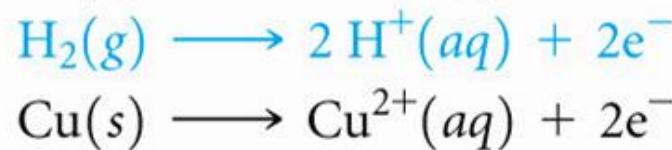
Hydrochloric acid

(盐酸) Aqueous
Reactions



Hydrogen

Copper



When an atom undergoes oxidation, it _____ electrons.

- a. gains
- b. loses
- c. retains
- d. balances

When an atom undergoes reduction, it _____ electrons.

- a. gains
- b. loses
- c. retains
- d. balances

What is the oxidation number of nitrogen (a) in aluminum nitride, AlN, and (b) in nitric acid, HNO₃?

氮化鋁

a.

- A. +1
- B. -1
- C. -2
- D. -3

b.

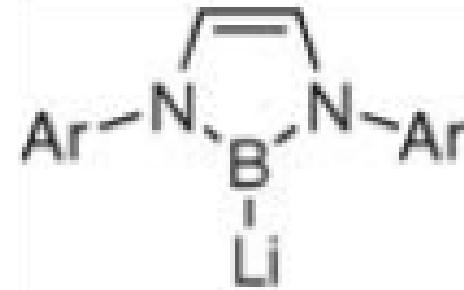
- A. +6
- B. +5
- C. +4
- D. -1

Determine the oxidation number of sulfur in **(a)** H₂S, **(b)** S₈, **(c)** SCl₂, **(d)** Na₂SO₃, **(e)** SO₄²⁻.

hydrogen sulfide, sulphur, sulfur chloride,
sodium sulfite, sulfate ion

The oxidation number of boron for the below compound?

- A. +1
- B. -1
- C. 0
- D. +3



When the oxidation-reduction reaction above is correctly balanced, the coefficients are

- a. 1, 2 \rightarrow 1, 1.
- b. 1, 3 \rightarrow 1, 2.
- c. 2, 3 \rightarrow 2, 3.
- d. 2, 6 \rightarrow 2, 3.

Does a reaction occur (a) when an aqueous solution of $\text{NiCl}_2(aq)$ is added to a test tube containing strips of metallic zinc, and (b) when $\text{NiCl}_2(aq)$ is added to a test tube containing $\text{Zn}(\text{NO}_3)_2(aq)$?

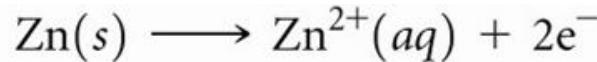
a.

- A. Yes
- B. No

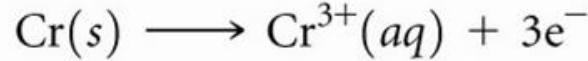
b.

- A. Yes
- B. No

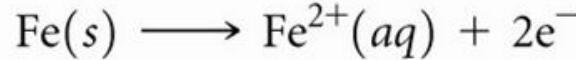
Zinc



Chromium



Iron



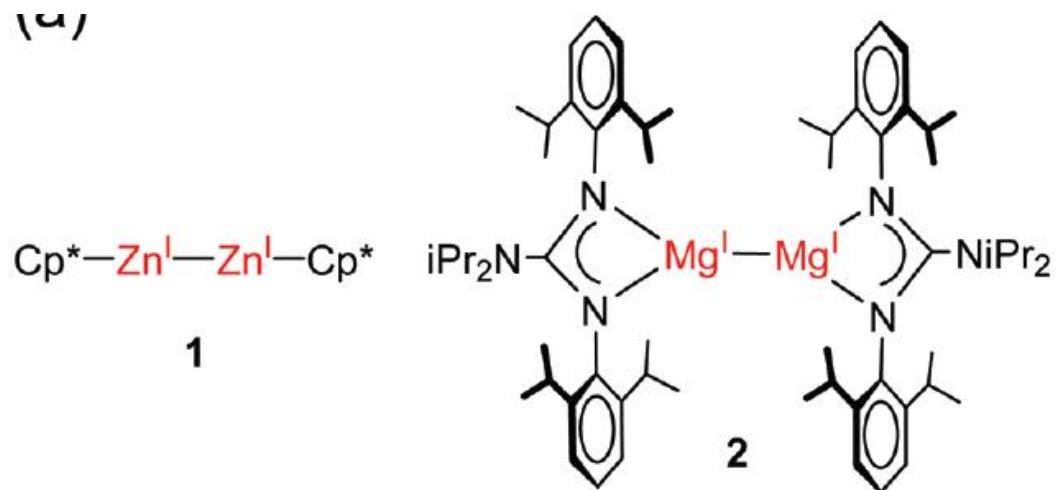
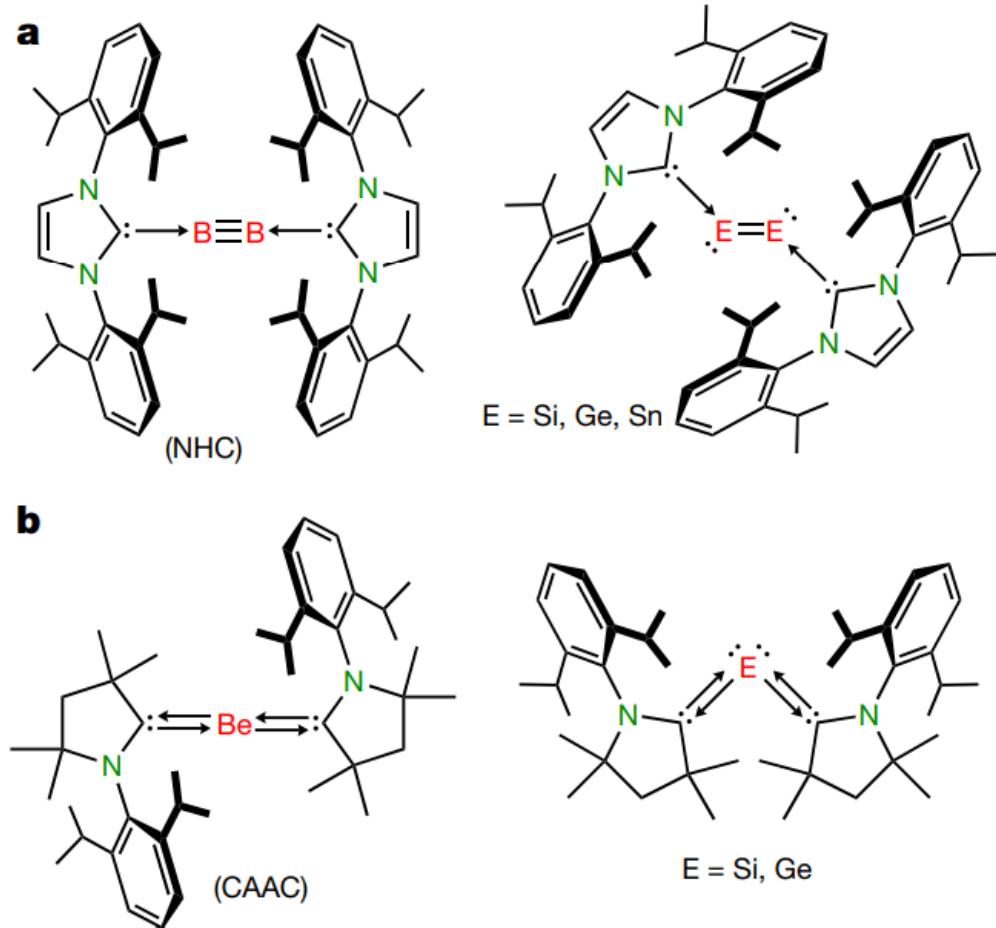
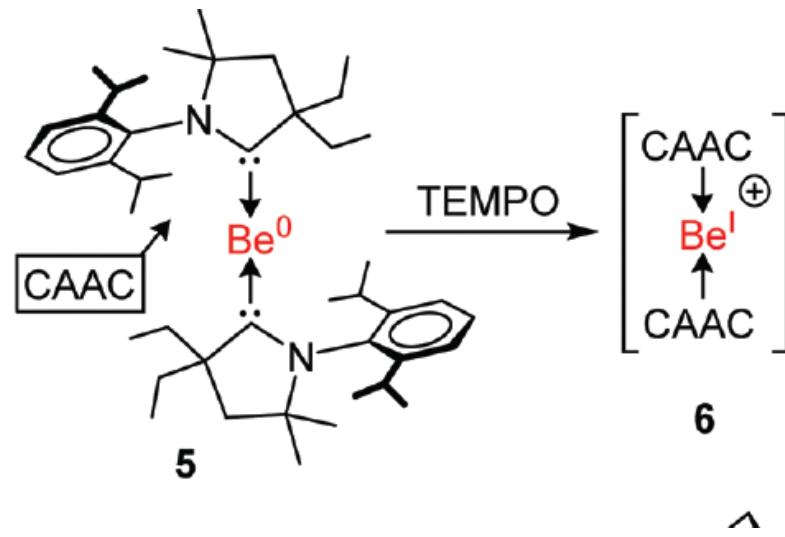
Cobalt



Nickel



Low-valent Metals (Extra Info.)



Chem. Commun.
2021, 9354.

Nature **2021**,
592, 717.



Low-valent Metals (Extra Info.) *Nature* 2021, 592, 717. Strongly reducing magnesium(0) complexes

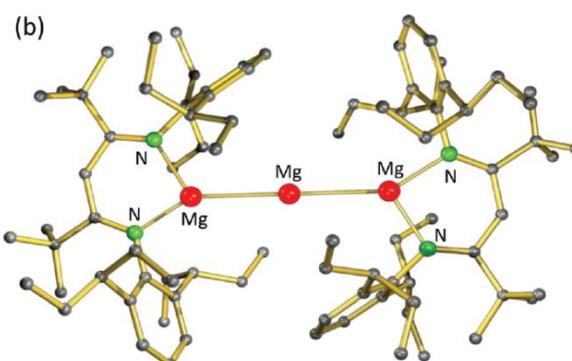
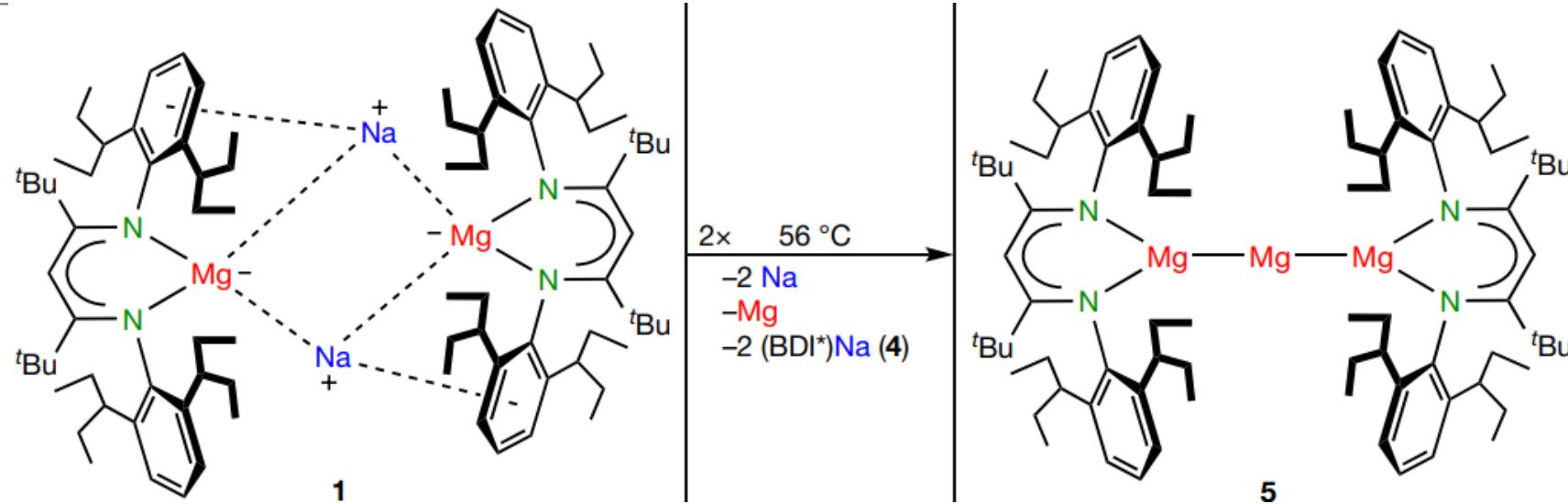
<https://doi.org/10.1038/s41586-021-03401-w>

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A complex of a metal in its zero oxidation state can be considered a stabilized, but



Aqueous
Reactions

Concentration

Molarity (摩尔浓度)

- Two solutions can contain the same compounds, but different amounts/proportions of the compounds.
- **Molarity** is one way to measure the **concentration** of a **solution** ($1\text{ M} = 1\text{ mol/L}$):

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{volume of solution in liters}}$$

$$\text{Mole} = \frac{\text{Mass}}{\text{Molecular/Formula Weight}}$$



1 Weigh out 39.9 g
(0.250 mol) CuSO₄

Mixing a Solution

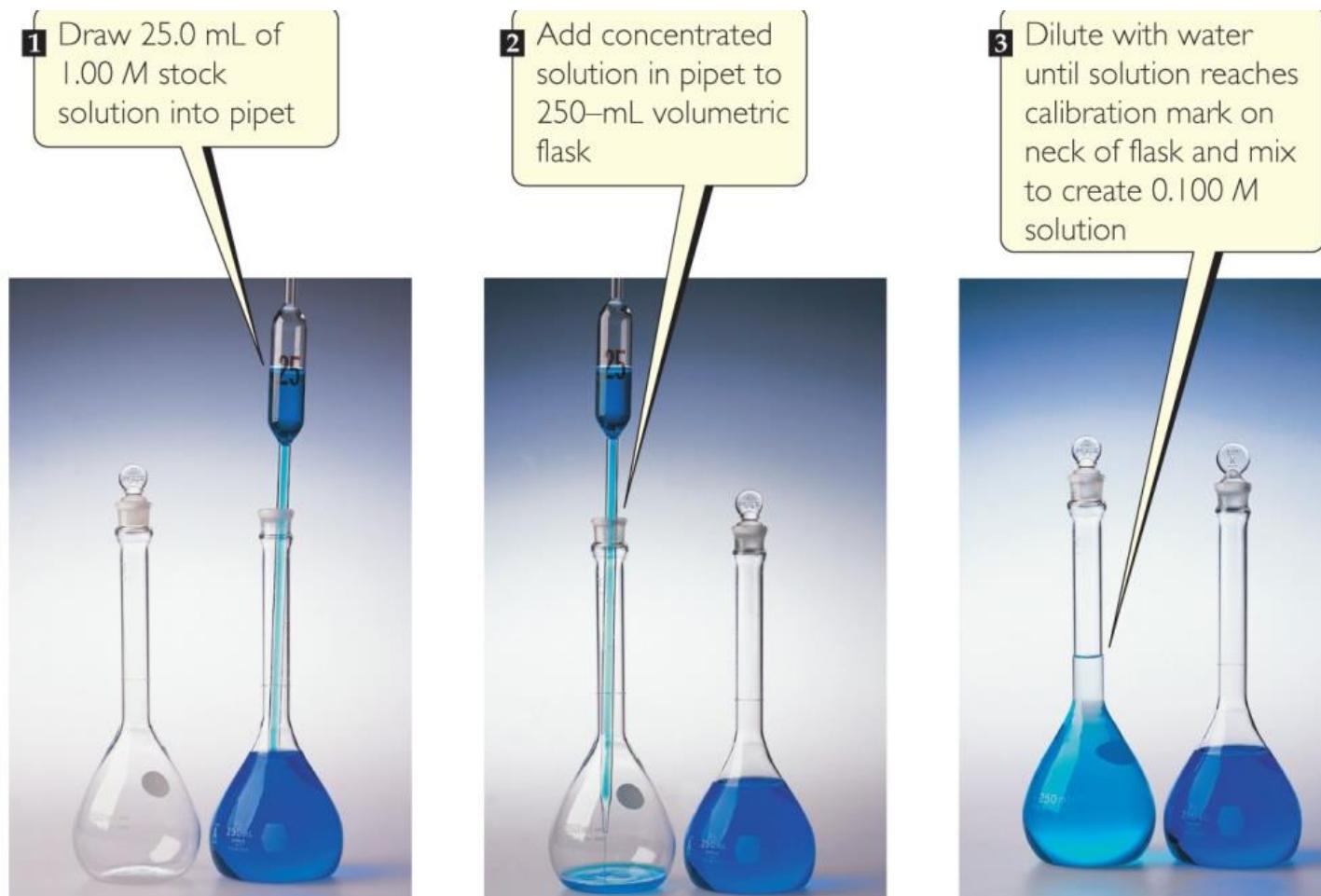
To prepare a solution of a known molarity:

1. one weights out a known mass of the solute → number of moles;
2. the solute is added to a volumetric flask (容量瓶);
3. solvent is added until reaching the line on the neck of the flask.



Dilution (稀释)

- Dilute a more **concentrated** solution by
 1. using a pipet (移液管) to deliver a volume of the solution to a new volumetric flask;
 2. adding solvent until reaching the line on the neck of the new flask.



The molarity of the new solution by dilution can be determined as follows (**the same amount of the solute (= $M \times V$) before and after the dilution**):

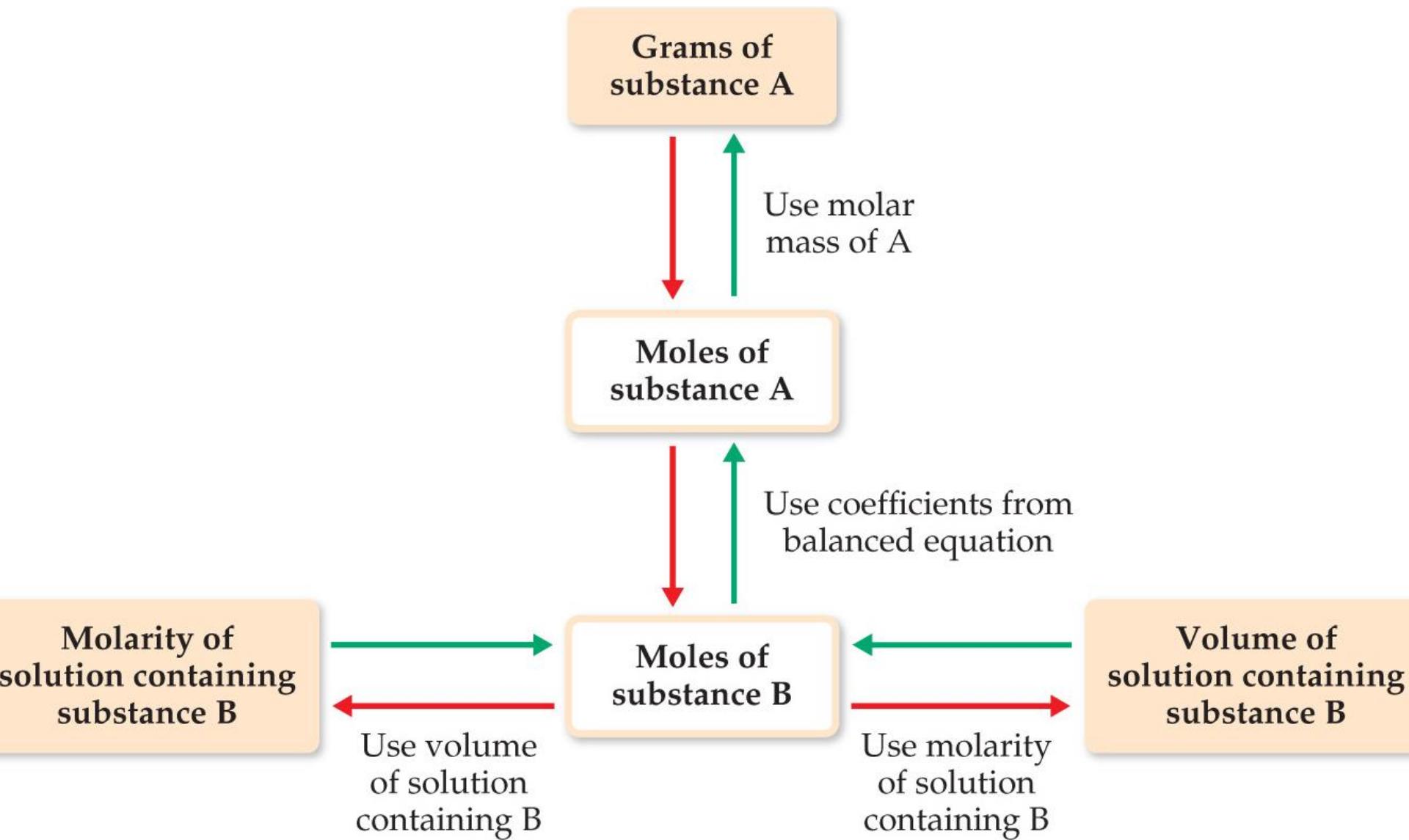
$$M_c \times V_c = M_d \times V_d,$$

where M_c & M_d are the **molarity** (M) of the **concentrated** (before) & **dilute** (after) solutions, respectively; V_c & V_d are the **volume** (V) of the two solutions.

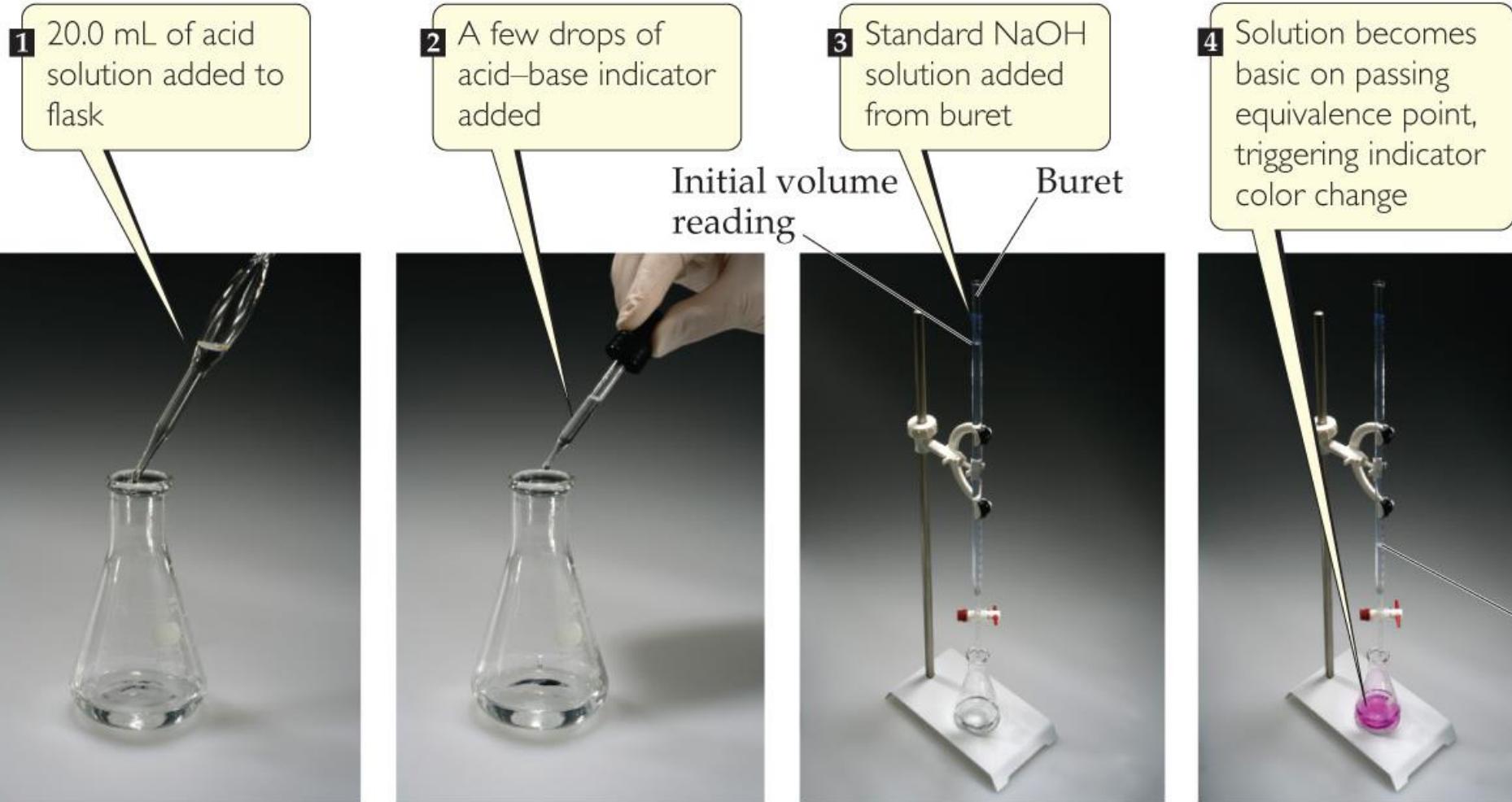
(When **NOT calculating molarity**, the above conversion does not require to use “M” & “L” units only, but the same units for M and V on the both sides are feasible):

$$mM^*L = mM^*L; M^*mL = M^*mL$$

Molarities in Stoichiometric Calculations



Titration (滴定)



Titration: an analytical technique to determine the concentration of a solute in a solution.
(equivalence point 当量点)

**Volume
standard solution
needed to reach
equivalence point**

Use molarity of
standard solution

**Moles solute
in standard
solution**

Use coefficients
from balanced
equation

**Concentration (molarity)
of unknown solution**

Use volume of
unknown solution

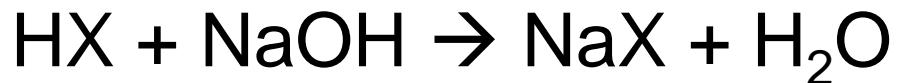
**Moles solute
in unknown
solution**

250.0 mL of 0.100 M AgNO_3 solution contains _____ grams of silver nitrate.

- a. 4.25
- b. 8.50
- c. 17.0
- d. 34.0

To make 250.0 mL of 0.500 M KI solution, _____ mL of 6.00 M KI must be used.

- a. 20.8
- b. 41.7
- c. 500.0
- d. 3000.0



232 mg of HX was titrated using 29.70 mL of 0.0965 M NaOH. What is element X?

- a. F
- b. Cl
- c. Br
- d. I

Key Summary

(Aqueous) Solution, Solvent, Solute

Dissociation: (Strong & Weak) Electrolyte; Conductivity

Precipitation: Solubility; Metathesis (Exchange) Reactions;
Molecular and (Net) Ionic Equations

Acid-Base: Arrhenius/Brønsted Acids & Bases; Neutralization;
Salt; Gas-forming Reactions

Oxidation-Reduction (Redox) Reaction: Oxidation
numbers; Displacement Reactions; Activity Series

Concentration: Molarity; Dilution; Titration

**Thank You for Your
Attention!
Any Questions?**