

## Precipitation Reactions

- A precipitate forms when a chemical reaction of solutions produces a solid product.
- A salt is an ionic compound. Ionic compounds result when metals bind with non-metals (elements from left side of Periodic Table with elements from right side of Periodic Table) or with the common anions ( $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ , etc.).

## Precipitation Reactions

- Salts may be either soluble or insoluble in water.
- When soluble salts dissolve in solution, they produce cations and anions in the aqueous phase.

## Precipitation Reactions

### Solubility Rules

- Salts containing  $\text{NH}_4^+$  or alkali metal cations (Li, Na, K, Rb, Cs, Fr) are soluble.
- Salts containing the following anions are soluble with the exceptions noted:

$\text{NO}_3^-$ : no exceptions

$\text{ClO}_4^-$ : no exceptions

$\text{HSO}_4^-$ : no exceptions

$\text{CH}_3\text{CO}_2^-$ : no exceptions

## Precipitation Reactions

### Solubility Rules (con't.)

- Salts containing the following anions are soluble with the exceptions noted:

$\text{Cl}^-$ :  $\text{AgCl}$ ,  $\text{Hg}_2\text{Cl}_2$ ,  $\text{PbCl}_2$

$\text{Br}^-$ :  $\text{AgBr}$ ,  $\text{Hg}_2\text{Br}_2$ ,  $\text{PbBr}_2$

$\text{I}^-$ :  $\text{AgI}$ ,  $\text{Hg}_2\text{I}_2$ ,  $\text{PbI}_2$

$\text{SO}_4^{2-}$ :  $\text{Hg}_2\text{SO}_4$ ,  $\text{PbSO}_4$ ,  $\text{CaSO}_4$ ,  $\text{SrSO}_4$ ,  
 $\text{BaSO}_4$

## Precipitation Reactions

### Solubility Rules (con't.)

- $\text{Ca}(\text{OH})_2$ ,  $\text{Sr}(\text{OH})_2$ , and  $\text{Ba}(\text{OH})_2$  are soluble—other hydroxide are insoluble (except group 1)

## Precipitation Reactions

Does a precipitate form when solutions of  $\text{NaCl}(\text{aq})$  and  $\text{AgNO}_3(\text{aq})$  are mixed?

1. What does the mixture look like initially?



## Precipitation Reactions

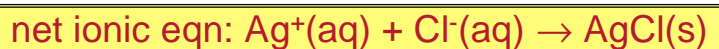
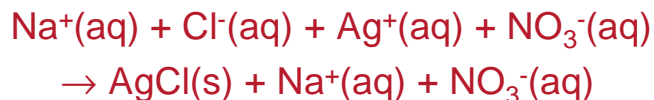
2. Form possible cation/anion combinations—do any of the resulting species form a precipitate?

Ions in solution:  $\text{Na}^+(\text{aq})$ ,  $\text{Ag}^+(\text{aq})$ ,  $\text{Cl}^-(\text{aq})$ ,  $\text{NO}_3^-(\text{aq})$

- $\text{NaCl}(\text{s})$ ? No—all salts with  $\text{Na}^+$  are soluble
- $\text{AgNO}_3(\text{s})$ ? No—all salts with  $\text{NO}_3^-$  are soluble
- $\text{NaNO}_3(\text{s})$ ? No— $\text{Na}^+$  and  $\text{NO}_3^-$  solubility rules
- $\text{AgCl}(\text{s})$ ? Yes—because this is one of the exceptions to the  $\text{Cl}^-$  family of soluble salts

## Precipitation Reactions

- The *net ionic equation* involves only those ions participating in the chemical reaction:



- $\text{Na}^+(\text{aq})$  and  $\text{NO}_3^-(\text{aq})$  are called *spectator ions* because they do not participate in the formation of products—their role is to balance the total electrical charge of the solution. Spectator ions are not included in the net ionic equation.

## Aqueous Solutions

- A solution is composed of two parts: the solute and the solvent.
  - The solute is the minor component of the solution.
  - The solvent is the major component of the solution and is the liquid into which the solute is added.
- Aqueous solutions are those in which water acts as the solvent.

## Concentration Units

- *Molarity* (M) is a very commonly used unit of concentration.  
molarity  $\equiv$  mol solute / L solution
- Units are mol L<sup>-1</sup>
- Note that the denominator is L total solution (total volume of solution), not L solvent (volume of solvent added).

## Molarity

Determine concentration of a solution in which 6.081 g  $\text{NaNO}_3$  is dissolved to a total volume of 843 mL.

1. Calculate moles of solute

a. molar mass of  $\text{NaNO}_3$

$$\text{Na: } 1 (22.990 \text{ g mol}^{-1}) = 22.990 \text{ g mol}^{-1}$$

$$\text{N: } 1 (14.007 \text{ g mol}^{-1}) = 14.007 \text{ g mol}^{-1}$$

$$\text{O: } 3 (15.999 \text{ g mol}^{-1}) = \underline{47.997 \text{ g mol}^{-1}}$$

$$\text{molar mass } (\text{NaNO}_3) = 84.994 \text{ g mol}^{-1}$$

## Molarity

1. Calculate moles of solute (con't.)

b. moles of  $\text{NaNO}_3$

$$6.081 \text{ g} / 84.994 \text{ g mol}^{-1} = 7.155 \times 10^{-2} \text{ mol}$$

2. Calculate molarity of solution

a. convert volume to L

$$843 \text{ mL} = 0.843 \text{ L}$$

b. calc M

$$7.155 \times 10^{-2} \text{ mol} / 0.843 \text{ L} = \boxed{8.49 \times 10^{-2} \text{ M}}$$

## Dilutions

- When diluting a solution by adding more solvent, the amount of solute does not change (you do not add or take away the solute), only the concentration changes.

$$C_1V_1 = C_2V_2$$

(C = concentration  
V = volume)

## Dilutions

50.0 mL of .650 M NaCl solution is diluted with 1000.0 mL of water. Determine concentration of final solution.

1.  $C_1V_1 = (0.650 \text{ M})(0.0500 \text{ L}) = 0.0325 \text{ mol NaCl}$

2. final volume =  $V_2 = 50.0 \text{ mL} + 1000.0 \text{ mL}$   
 $= 1050.0 \text{ mL}$

3.  $C_2V_2 = C_1V_1 = 0.0325 \text{ mol NaCl}$   
 $C_2 = C_1V_1 / V_2 = 0.0325 \text{ mol} / 1.0500 \text{ L}$   
 $= 3.10 \times 10^{-2} \text{ M}$

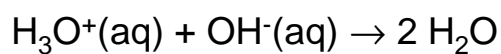
## Acid-Base Reactions

- The simplest definitions of acid and base are:

An acid donates H<sup>+</sup> ion

A base accepts H<sup>+</sup> ion

- An acid reacts with a base to form water:



acid

base

## Acid-Base Reactions

- The hydronium ion, H<sub>3</sub>O<sup>+</sup>, is actually a hydrated hydrogen ion, H<sup>+</sup>·H<sub>2</sub>O. (H<sup>+</sup> is the chemical formula of a proton, and protons do not hang out in solution alone.)
- Many bases form hydroxide ion, OH<sup>-</sup>, when dissolved in water.

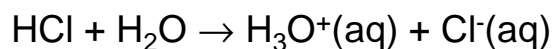


## Strong and Weak Acids

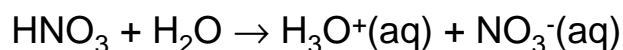
- A “strong” acid is a compound that dissociates nearly completely in solution to form hydronium ion.

### Strong acids

Hydrochloric acid:



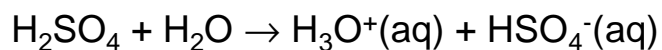
Nitric acid:



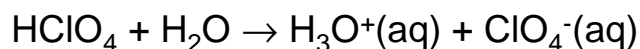
## Strong and Weak Acids

### Strong acids (con't.)

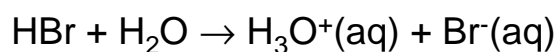
Sulfuric acid:



Perchloric acid:



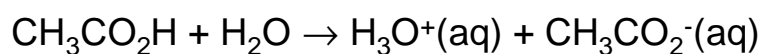
Hydrobromic acid:



## Strong and Weak Acids

- A “weak” acid dissociate only partially in water to form hydronium ion.

Acetic acid:



A solution of acetic acid contains all three species:  $\text{H}_3\text{O}^+(\text{aq})$ ,  $\text{CH}_3\text{CO}_2^-(\text{aq})$ , and  $\text{CH}_3\text{CO}_2\text{H}(\text{aq})$ .

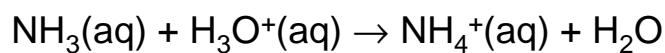
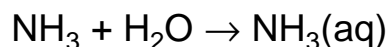
## Strong and Weak Bases

- A “strong” base produces stoichiometric quantities of  $\text{OH}^-(\text{aq})$ .

Group 1 hydroxides: NaOH, KOH, etc.

Some Group 2 hydroxides:  $\text{Ca}(\text{OH})_2$ ,  $\text{Sr}(\text{OH})_2$ , and  $\text{Ba}(\text{OH})_2$

- A “weak” base accepts a proton from  $\text{H}_3\text{O}^+$ , but not water.



## Acid-Base Titrations

- Titrations use a solution of known concentration to determine the concentration of an unknown solution.
- Titrations may be performed with either an acid or a base as the *titrant*—the known solution employed in the titration.
- A acid of known concentration is used to determine a basic solution: a base of known concentration is used to determine an acidic solution.

## Acid-Base Titrations

- The *equivalence point* (the textbook calls this the stoichiometric point) of the titration is reached when:  
moles  $\text{H}_3\text{O}^+(\text{aq}) = \text{moles OH}^-(\text{aq})$
- If we know (a) the concentration of the titrant, (b) the volume of titrant used, and (c) the volume of the unknown solution, we can determine the concentration of the unknown solution.

## Acid-Base Titrations

Determine the concentration of acetic acid in a sample of vinegar:



### Experimental Conditions

15.21 g NaOH dissolved in 500.0 mL H<sub>2</sub>O

25.0 mL of vinegar initially in flask

Volume of NaOH soln. used = 29.97 mL

## Acid-Base Titrations

Determine the concentration of acetic acid in a sample of vinegar:

### NaOH Titrant

$$(15.21 \text{ g NaOH}) / (39.997 \text{ g mol}^{-1}) = .3803 \text{ mol}$$

$$(.3803 \text{ mol}) / (.500 \text{ L}) = .7606 \text{ M NaOH soln.}$$

$$(.7606 \text{ M NaOH}) (.02997 \text{ L}) = .02280 \text{ mol NaOH}$$

at equivalence point

## Acid-Base Titrations

Determine the concentration of acetic acid in a sample of vinegar:

### Acetic Acid

At equivalence point:



25.0 mL of vinegar contains .02280 mol  
 $\text{CH}_3\text{CO}_2\text{H}$ :

$$[\text{CH}_3\text{CO}_2\text{H}] = (.02280 \text{ mol}) / (.025 \text{ L}) = .912 \text{ M}$$

## Oxidation-Reduction Reactions

- Oxidation-reduction reactions involve the transfer of electrons between reactants and products.
- The *oxidation number* of an atom is the electrical charge on that atom.

$\text{O}_2$ : O has an oxidation number of 0

$\text{O}^{2-}$ : O has an oxidation number of -2

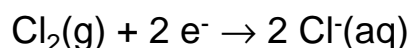
$\text{O}^+$ : O has an oxidation number of +1

## Oxidation-Reduction Reactions

- Oxidation corresponds to a loss of electrons—the *oxidation number* of the atom increases.



- Reduction corresponds to a gain of electrons—the *oxidation number* of the atom decreases.



## Oxidation-Reduction Reactions

### Rust Formation



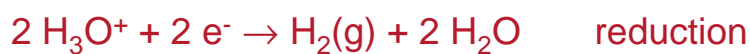
$\text{O}^0$  reduced to  $\text{O}^{2-}$

The electrons produced in the oxidation of Fe are used in the reduction of  $\text{O}_2$ .



## Oxidation-Reduction Reactions

- *Redox* reactions (oxidation-reduction reactions) can be separated into *half-reactions*—one reaction for the oxidation process and one reaction for the reduction process:

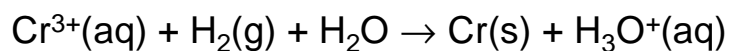


## Balancing Redox Reactions

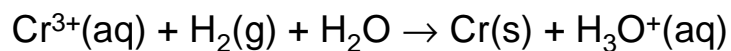
- *Redox* reactions can be most easily balanced by separating the reaction into its half reactions (one for oxidation and one for reduction), and then balancing the electrons transferred in the process.

## Balancing Redox Reactions

### Example



**Step 1:** Which species is oxidized and which species is reduced?



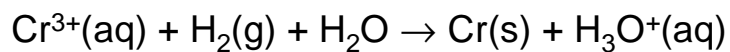
Oxid. State: +3                      0                      +1 -2                      0                      +1 -2

Cr is reduced (+3 → 0)

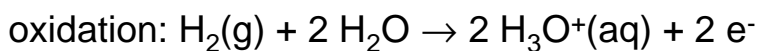
H from  $\text{H}_2(\text{g})$  is oxidized (0 → +1)

## Balancing Redox Reactions

### Example



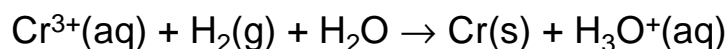
**Step 2:** Write half reactions for oxidation and reduction processes



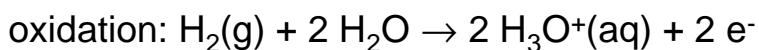


## Balancing Redox Reactions

### Example



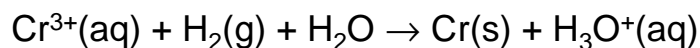
### Step 3: Balance number of electrons transferred



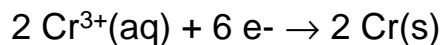
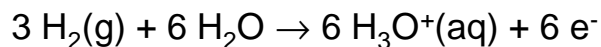
If we multiply the oxidation reaction by 3 and the reduction reaction by 2, then each reaction involves a total of 6 electrons.

## Balancing Redox Reactions

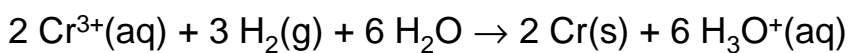
### Example



### Step 3: Balance number of electrons transferred

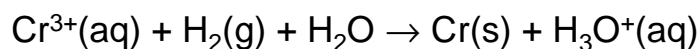


Summing the two half reactions give the net overall reaction:

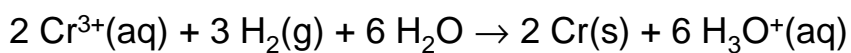


## Balancing Redox Reactions

### Example



**Step 4:** Check that atoms and charges are balanced



2 Cr on each side

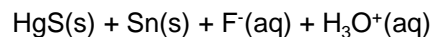
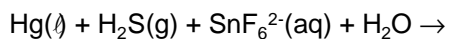
18 H on each side

6 O on each side

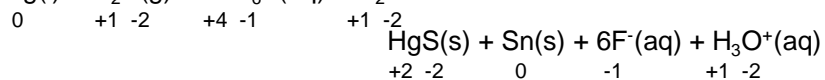
+6 charge on reactants; +6 charge on products

## Balancing Redox Reactions

### Example



**Step 1:** Which species is oxidized and which species is reduced?

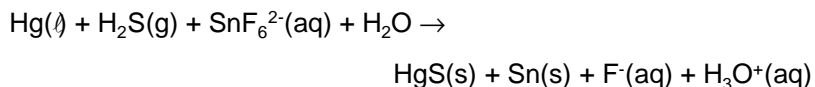


Oxidation: Hg is oxidized from 0 to +2 oxidation state

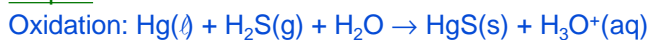
Reduction: Sn is reduced from +4 to 0 oxidation state

## Balancing Redox Reactions

### Example



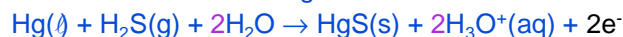
Step 2: Write half reactions for oxidation and reduction processes



mass balance: Hg, S, and O are balanced as written, but not H

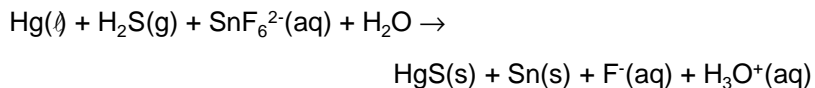


add electrons to achieve charge balance:



## Balancing Redox Reactions

### Example



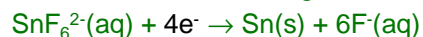
Step 2: Write half reactions for oxidation and reduction processes



mass balance: Sn is balanced as written, but not F

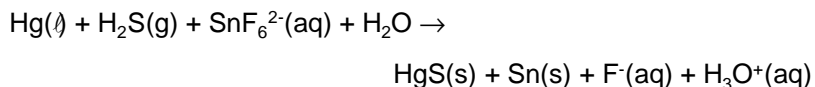


add electrons to achieve charge balance:

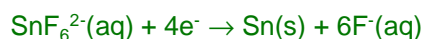
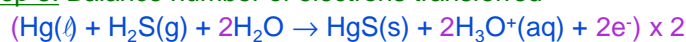


## Balancing Redox Reactions

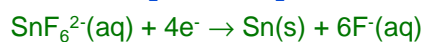
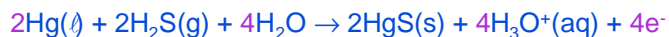
### Example



### Step 3: Balance number of electrons transferred

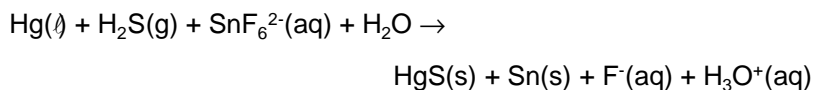


Result:

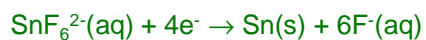
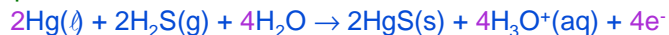


## Balancing Redox Reactions

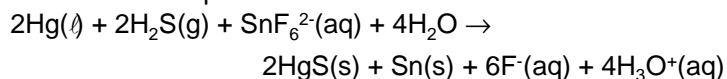
### Example



### Step 3: Balance number of electrons transferred

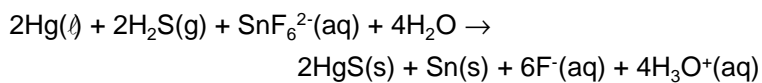


Sum of chemical equations:



## Balancing Redox Reactions

### Example



### Step 4: Check mass and charge balance

	Reactants	Products
Hg	2	2
S	2	2
Sn	1	1
F	6	6
H	12	12
O	4	4
charge	-2	-6 + (+4) = -2

## Oxidation-Reduction Reactions

TABLE 5.5 Activity Series of Metals

Displace H <sub>2</sub> from H <sub>2</sub> O(ℓ), steam, or acid	Li K Ba Sr Ca Na
Displace H <sub>2</sub> from steam, or acid	Mg Al Mn Zn Cr
Displace H <sub>2</sub> from acid	Fe Ni Sn Pb
	H <sub>2</sub>
Do not displace H <sub>2</sub> from H <sub>2</sub> O(ℓ), steam, or acid	Sb Cu Hg Ag Pd Pt Au

↑  
Ease of oxidation increases

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