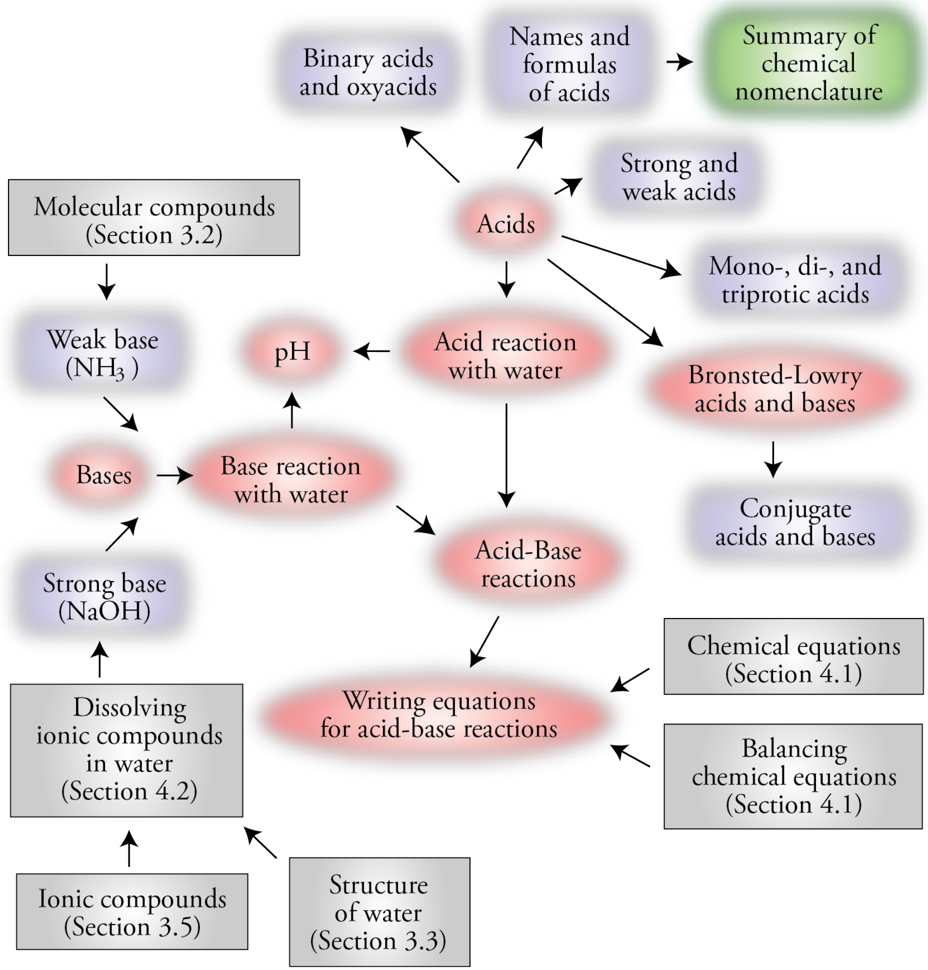
Chapter 5
Acids, Bases, and Acid-Base Reactions

An Introduction to Chemistry

by Mark Bishop

Chapter Map



Binary acids and oxyacids
Names and formulas of acids
Summary of chemical nomenclature
Strong and weak acids
Molecular compounds (Section 3.2)
Acids
Mono-, di-, and triprotic acids
Weak base (NH_3)
pH
Acid reaction with water
Bronsted-Lowry acids and bases
Bases
Base reaction with water
Conjugate acids and bases
Acid-Base reactions
Strong base (NaOH)
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Writing equations for acid-base reactions
Dissolving ionic compounds in water (Section 4.2)
Balancing chemical equations (Section 4.1)
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Arrhenius Acid Definition

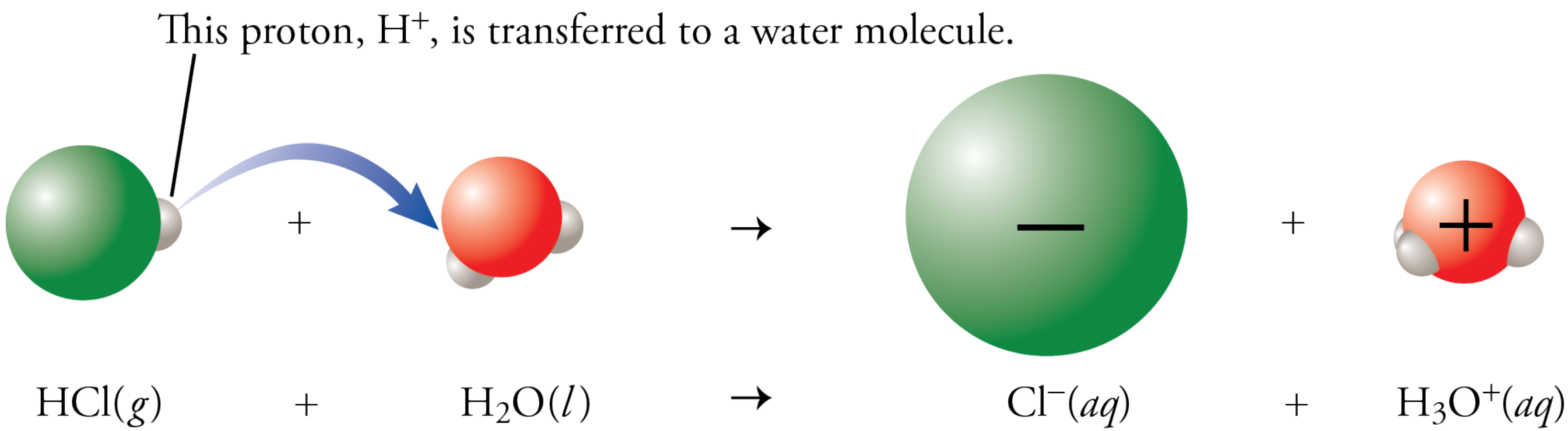
- An ***acid*** is a substance that generates hydronium ions, H_3O^+ (often described as H^+), when added to water.
- An ***acidic solution*** is a solution with a significant concentration of H_3O^+ ions.

Characteristics of Acids

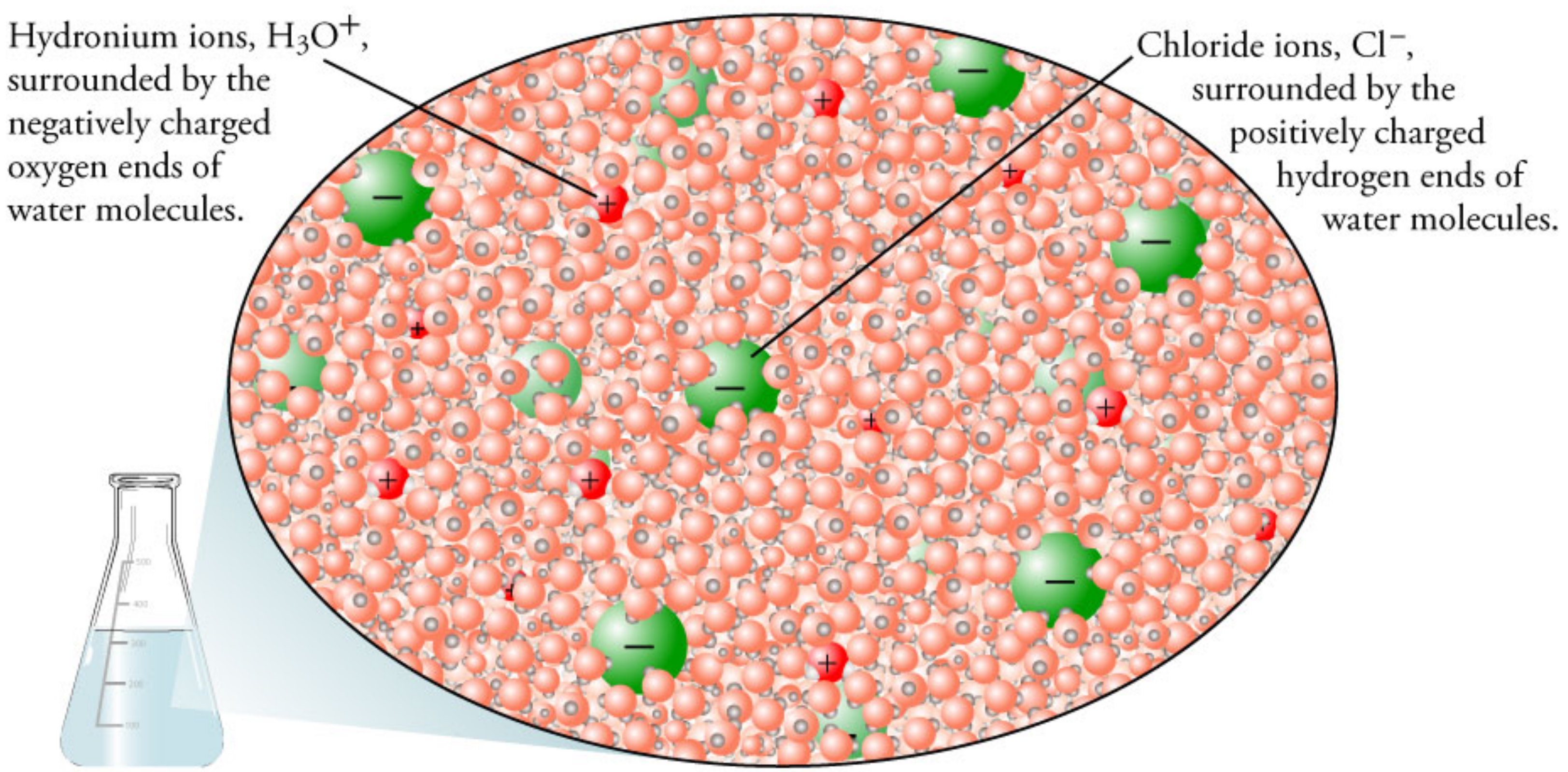
- Acids have a sour taste.
- Acids turn litmus from blue to red.
- Acids react with bases.

Strong Acid and Water

When HCl dissolves in water, hydronium ions, H_3O^+, and chloride ions, Cl^-, ions form.



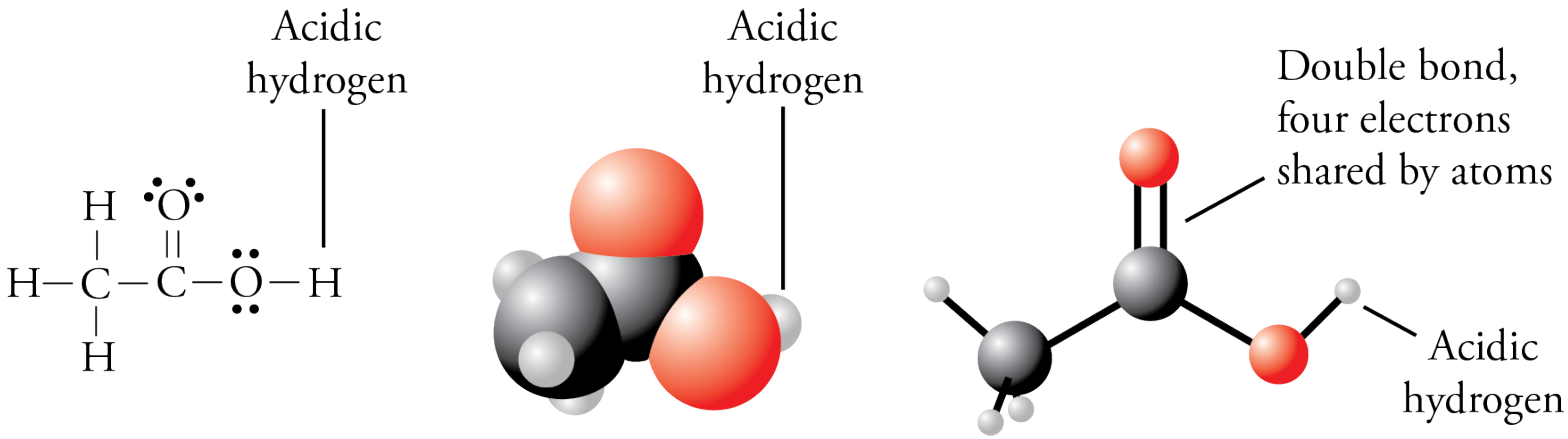
Solution of a Strong Acid



Types of Acids

- Binary acids have the general formula of HX(aq)
  - HF(*aq*) and HCl(*aq*)
- Oxyacids have the general formula $H_aX_bO_c$.
  - HNO_3 and H_2SO_4
- Organic acids, which are also called carbon-based acids or carboxylic acids
  - $HC_2H_3O_2$

Acetic Acid

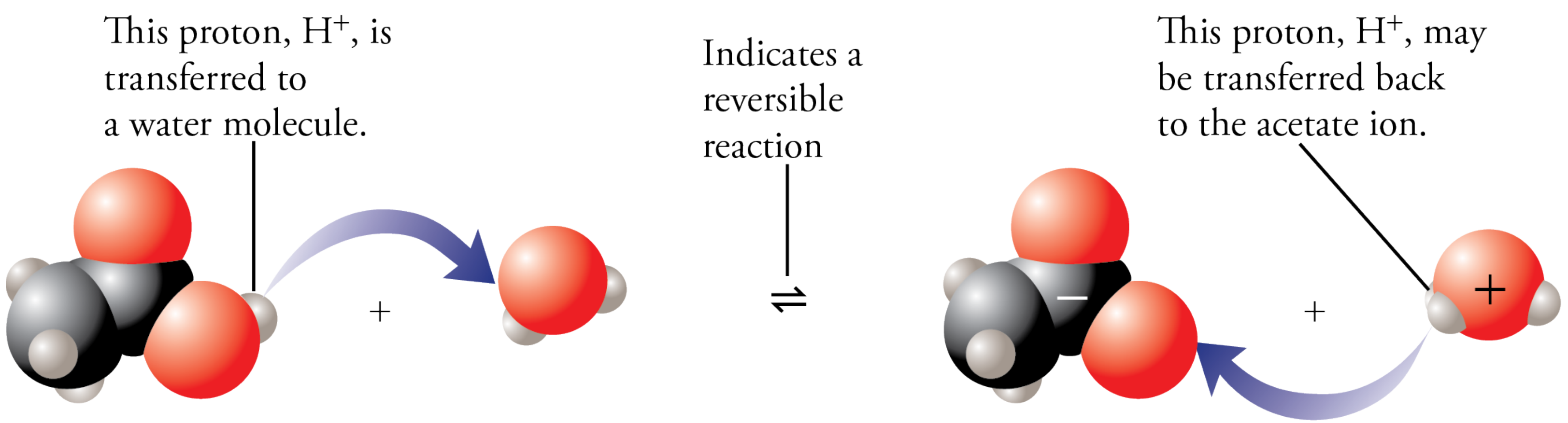

Acidic hydrogen
Acidic hydrogen
Double bond, four electrons shared by atoms
Acidic hydrogen

Monoprotic and Polyprotic Acids

- If each molecule of an acid can donate one hydrogen ion, the acid is called a **monoprotic acid**.
- If each molecule can donate two or more hydrogen ions, the acid is a **polyprotic acid**.
- A **diprotic acid**, such as sulfuric acid, H_2SO_4, has two acidic hydrogen atoms.
- Some acids, such as phosphoric acid, H_3PO_4, are **triprotic acids**.

Weak Acid and Water

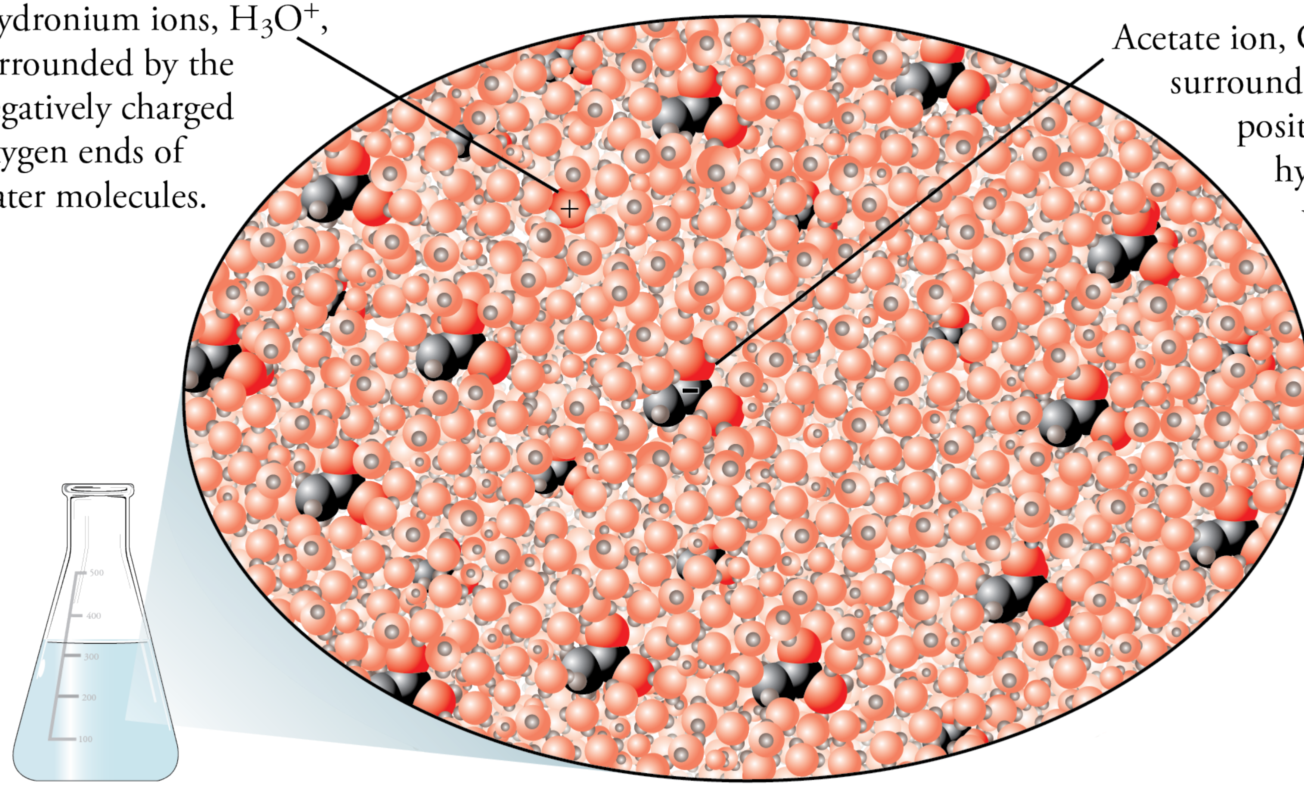
Acetic acid reacts with water in a reversible reaction, which forms hydronium and acetate ions.



$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons C_2H_3O_2^-(aq) + H_3O^+(aq)$$

Solution of Weak Acid

In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules, $HC_2H_3O_2$, as acetate ions, $C_2H_3O_2^-$.



Strong and Weak Acids

- ***Weak Acid*** = due to a reversible reaction with water, generates significantly less than one H_3O^+ for each molecule of acid added to water.
- ***Strong Acid*** = due to a completion reaction with water, generates close to one H_3O^+ for each acid molecule added to water.

Strong and Weak Acids

For every 250 molecules of the weak acid acetic acid, $HC_2H_3O_2$, added to water, there are about

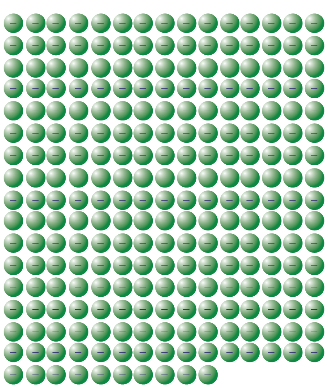
$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons C_2H_3O_2^-(aq) + H_3O^+(aq)$$

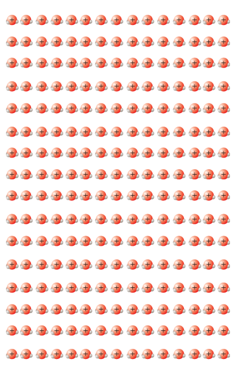
249 uncharged acetic acid molecules — One acetate ion — One hydronium ion

For every 250 molecules of the strong acid hydrochloric acid, HCl, added to water, there are about

$$HCl(g) + H_2O(l) \rightarrow Cl^-(aq) + H_3O^+(aq)$$

Zero uncharged HCl molecules — 250 chloride ions — 250 hydronium ions





Acid Animation and Tutorial

- There is an animation on the textbook's website that will give you a better understanding of weak and strong acids.

https://preparatorychemistry.com/acids_Canvas.html

Sulfuric Acid

$$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

$$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$$

Acid Summary

	Strong	Weak
Binary acid	hydrochloric acid, $HCl(aq)$	Hydrofluoric acid
Oxyacid	nitric acid, HNO_3 sulfuric acid, H_2SO_4	other acids with $H_aX_bO_c$
Organic acid	none	acetic acid, $HC_2H_3O_2$

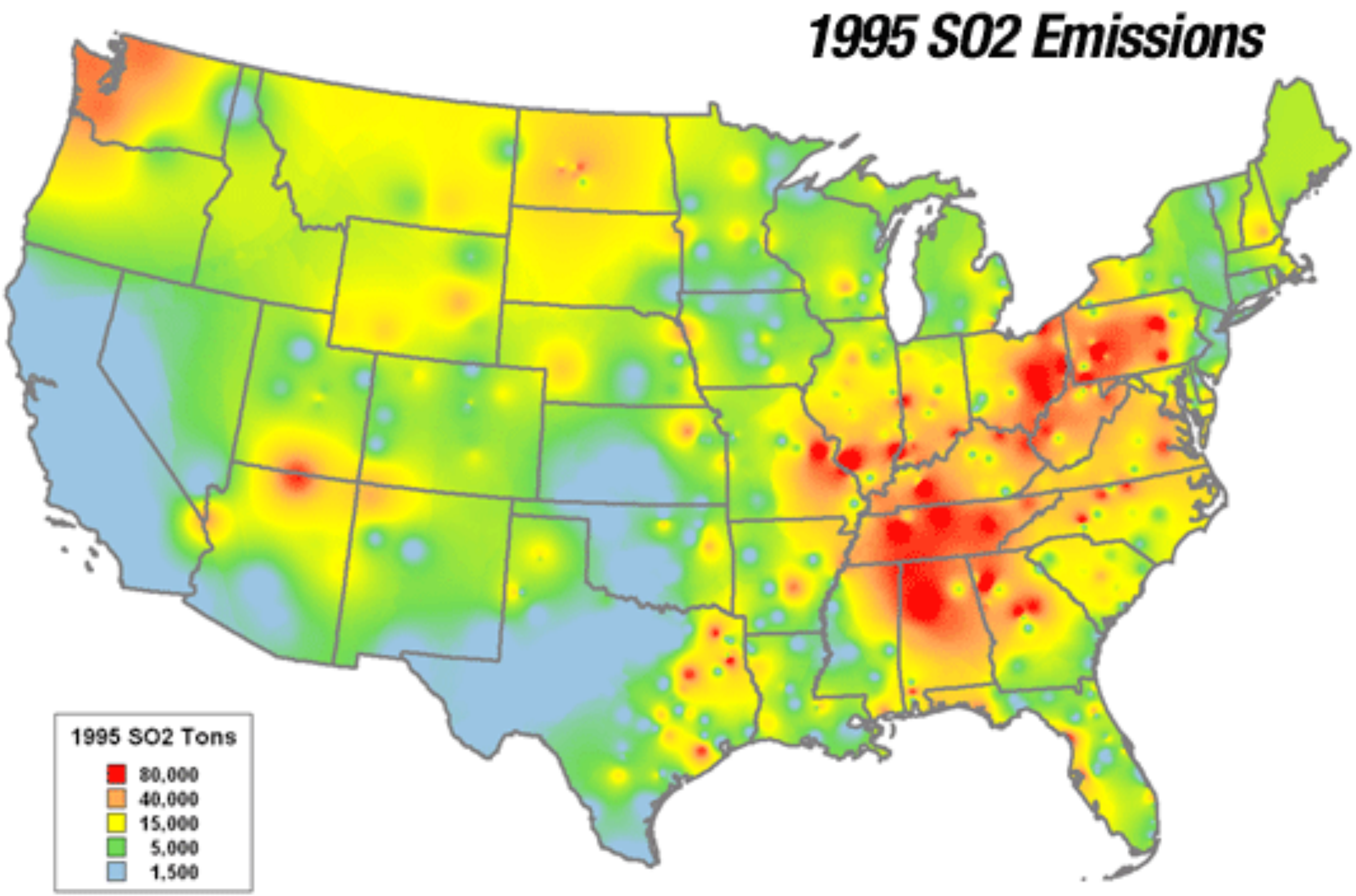
Acid Rain

- Large quantities of sulfur dioxide, SO_2, are formed and released into the air from burning sulfur-containing substances in coal in power plants and in metal ores in smelting, which involves heating of metal ores to extract metals.
- SO_2 forms sulfuric acid, H_2SO_4, in the atmosphere, which can dissolve in the clouds and form acid rain.
- Sulfuric acid forms hydronium ions.

$$H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$$

$$HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$$

1995 SO2 Emissions



NO_x and Nitric Acid

- The combination of air at high temperature, perhaps with a metal to act as a catalyst, leads to the formation of nitrogen monoxide, NO, and nitrogen dioxide, NO_2, often summarized as "NOx".
- Transportation and industry are major sources of nitrogen oxides.
- The NO_2 forms nitric acid in the atmosphere, which is a strong acid.

$$HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$$

Acids and Acid Precursors

- Sulfur dioxide (SO_2) $\rightarrow$ sulfuric acid (H_2SO_4)
  - primarily from coal burning and smelting
- Nitrogen oxides (NO, NO_2) $\rightarrow$ nitric acid (HNO_3)
  - primarily from high-temperature combustion

strong acids

- Formic and acetic acids (HCO_2H, CH_3CO_2H)
  - primarily from biomass burning, mostly in Africa and South America
- Carbonic acid ($CO_2 \rightarrow H_2CO_3$)
  - from CO_2 in atmosphere, responsible for acidity of pristine precipitation

weak acids

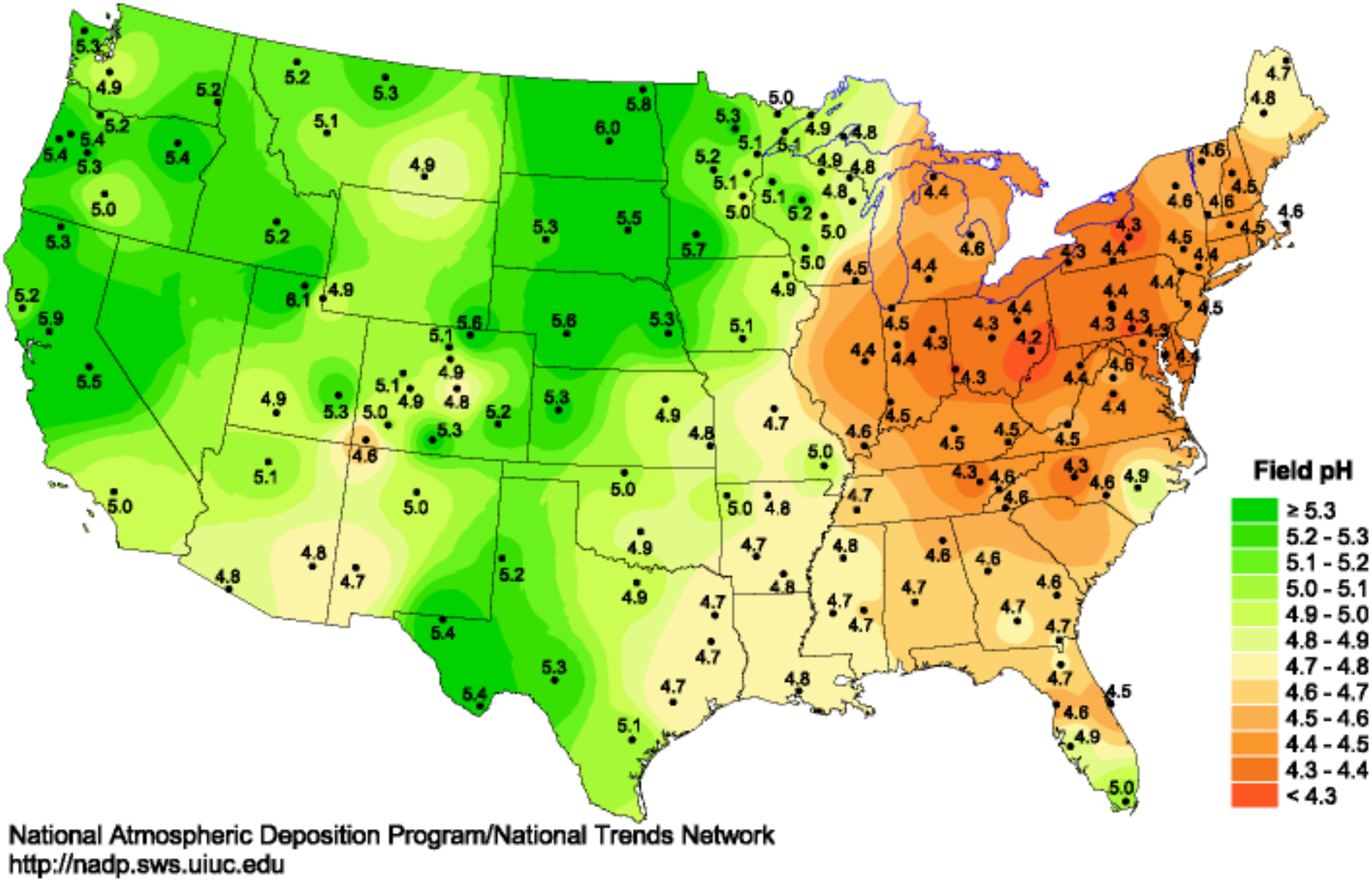
pH

- The pH scale can be used to describe the acidity and basicity of dilute solutions of acid and base.
- Acidic solutions have pHs from 0 to 7.
- The lower the pH, the more acidic the solution, and a decrease in one pH unit is associated with an increase of 10-times the hydronium ion concentration.
- Therefore, small changes in pH reflect significant changes in H_3O^+ concentration.

Pristine Rain and Acid Rain

- Due to acids dissolved in natural rain, such as the carbonic acid that forms when CO_2 dissolves in water, pristine or unpolluted rain has a pH of about 5.6.
- Acid rain can have a pH close to 4.

Rain pH 1999


Field pH
≥ 5.3
5.2 - 5.3
5.1 - 5.2
5.0 - 5.1
4.9 - 5.0
4.8 - 4.9
4.7 - 4.8
4.6 - 4.7
4.5 - 4.6
4.4 - 4.5
4.3 - 4.4
< 4.3
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Impacts

- Lowering pH can damage freshwater ecosystems, forests, agriculture, human health, buildings, and other property.

Damage to Human Health

- More acidic rain dissolves more toxic metals in the soil, which increases the level of these metals in water systems, leading to consumption of fish with elevated concentrations of toxic metals (Al, Pb, Cd, Hg, Cu, Zn).
- Corrosion of pipes results in excess levels of Cu, Zn, Pb in drinking water.

Damage to Buildings and Property

- Acids etch glass, damage roofing and other building materials, and damage plastics and paint (especially automotive paint).
- Carbonate stones (marble, limestone, etc.), cement, mortar are dissolved by acids:

$$CaCO_3(s) + 2H_3O^+(aq)$$

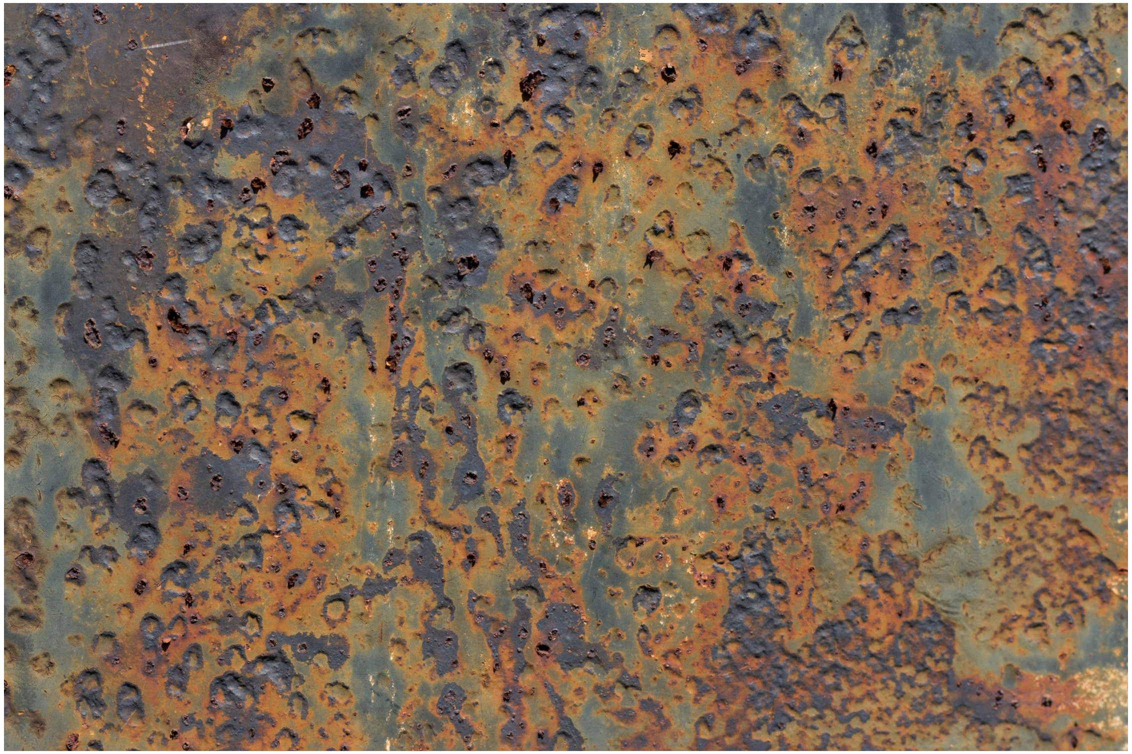
$$\rightarrow Ca^{2+(}aq) + CO_2(g) + 3H_2O(l)$$

Damage to Art

The statues on the left were transported by William Randolph Hearst to his home in San Simeon, California. Because it so rarely rains there, and because San Simeon is far from any major sources of pollution, these statues are in much better condition than the similar statues found elsewhere, such as the one on the right, that have been damaged by acid rain.

Effects on Metals

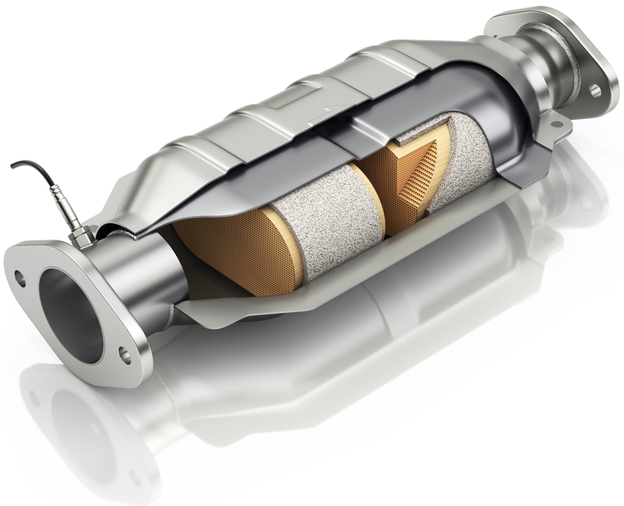
- Acid rain speeds the corrosion of metals.



Automobile Catalytic Converters

- Catalytic converters can convert up to 95% of the NO and NO_2 back to nitrogen and oxygen.

$$2NO \rightarrow N_2 + O_2 \qquad\qquad 2NO_2 \rightarrow N_2 + 2O_2$$



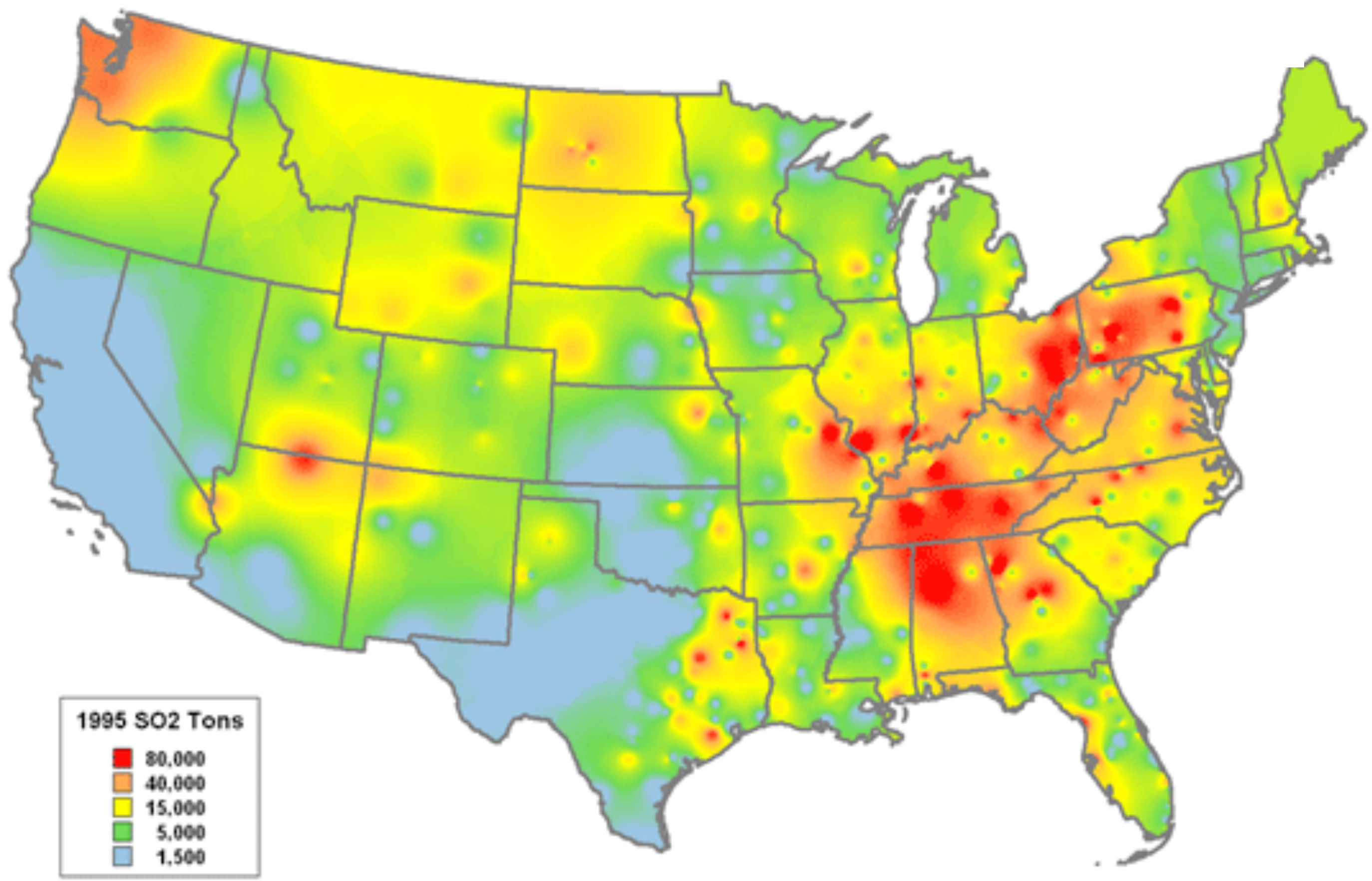
Mitigation - Sulfur

- Switch from coal to natural gas (0.001% S)
- Switch to low-sulfur coal
- Power plant scrubbers can use CaO (lime), $CaCO_3$ (limestone), or $Ca(OH)_2$ (lime) to remove SO_2 from the stack gases.

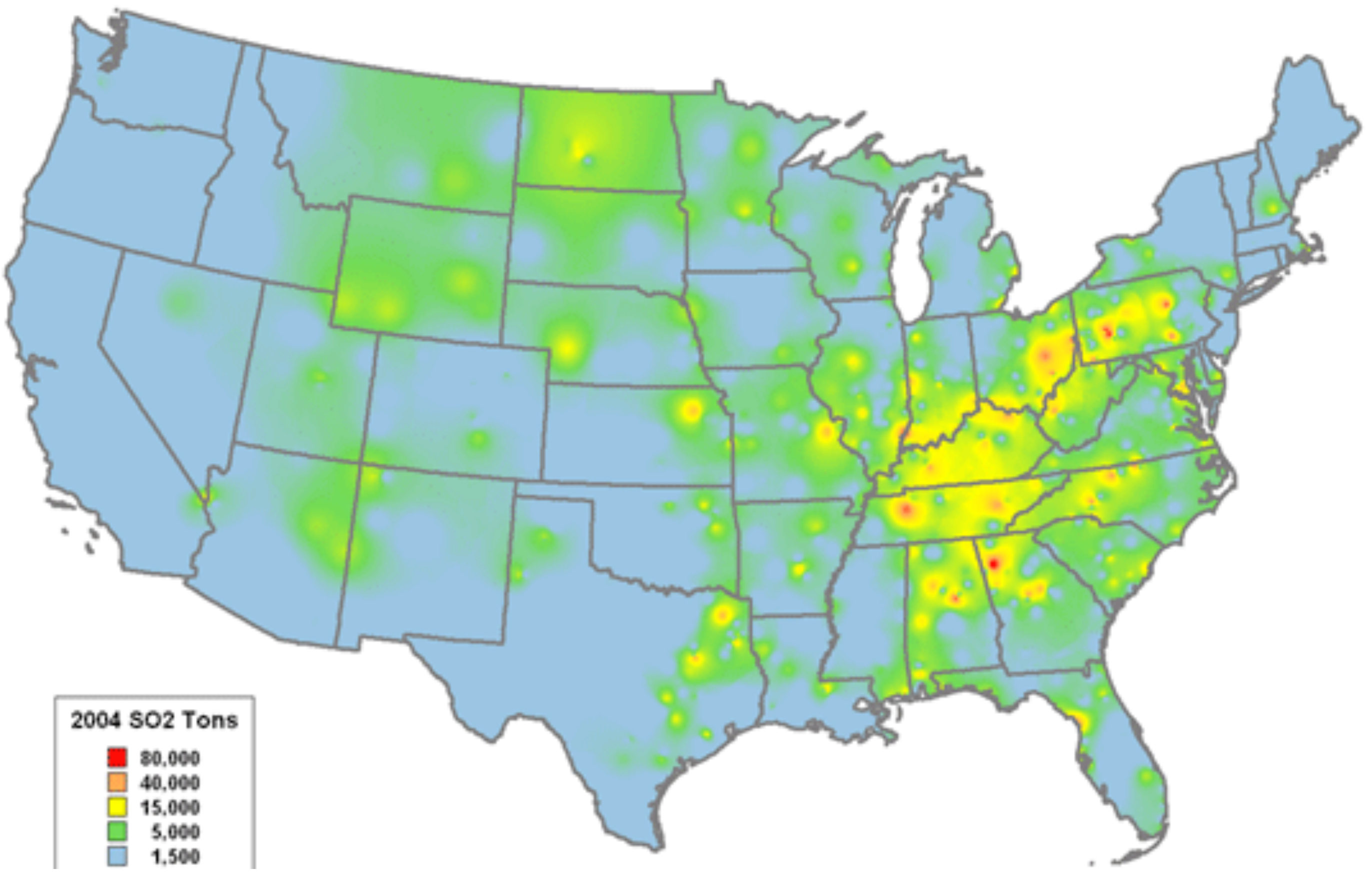
SO_2 Emissions Reduction

- Due largely to the US EPA's Acid Rain Program, the U.S. had a 33% decrease in SO_2 emissions between 1983 and 2002.

1995 SO_2 Emissions



2004 SO_2 Emissions



Two Types of Acids

- Binary acids, such as hydrochloric acid, $HCl(aq)$.
- Oxyacids, such as sulfuric acid, H_2SO_4, and nitric acid, HNO_3.

Names and Formulas of Binary Acids

- Names have the general form of *hydro(root)ic acid*, such as hydrochloric acid.
- The formulas are usually followed by (*aq*), such as HCl(*aq*).

Binary Acids

Formula	Named as Binary Covalent Compound	Acid Formula	Named as Binary acid
HF or HF(*g*)	hydrogen monofluoride or hydrogen fluoride	HF(*aq*)	hydrofluoric acid
HCl or HCl(*g*)	hydrogen monochloride or hydrogen chloride	HCl(*aq*)	hydrochloric acid
HBr or HBr(*g*)	hydrogen monobromide or hydrogen bromide	HBr(*aq*)	hydrobromic acid
HI or HI(*g*)	hydrogen moniodide or hydrogen iodide	HI(*aq*)	hydriodic acid

Names and Formulas for Oxyacids

- If enough H^+ ions are added to a (root)ate polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.
  - Nitrate, NO_3^-, goes to nitric acid, HNO_3.
  - Sulfate, SO_4^{2-}, goes to sulfuric acid, H_2SO_4. (Note the -ur- in the name.)
  - Phosphate, PO_4^{3-}, goes to phosphoric acid, H_3PO_4. (Note the -or- in the name.)

Oxyacids

Oxyanion Formula	Oxyanion Name	Oxyacid Formula	Oxyacid Name
NO_3^-	nitrate	HNO_3	nitric acid
$C_2H_3O_2^-$	acetate	$HC_2H_3O_2$	acetic acid
SO_4^{2-}	sulfate	H_2SO4_4	sulfuric acid (Note that the whole name *sulfur* is used in the oxyacid name.)
CO_3^{2-}	carbonate	H_2CO_3	carbonic acid
PO_4^{3-}	phosphate	H_3PO_4	phosphoric acid (Note that the root of phosphorus in an oxyacid name is *phosphor*-.)

Memorized Names

Name	Formula	Name	Formula
water	H_2O	ammonia	NH_3
methane	CH_4	ethane	C_2H_6
propane	C_3H_8	methanol (methyl alcohol)	CH_3OH
ethanol (ethyl alcohol)	C_2H_5OH	2-propanol (isopropyl alcohol)	C_3H_7OH

Periodic Table

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1											1 H							2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

https://preparatorychemistry.com/Bishop_periodic_table.pdf

Chemical Nomenclature

- General procedure for naming compounds
  - **Step 1:** Decide what type of compound the name or formula represents.
  - **Step 2:** Apply the rules for writing the name or formula for that type of compound.

Table 6.13 (atoms) or 5.5 (chemistry)

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

Practice

- The web address below will take you to tool that will help you recognize different types of substances.

https://preparatorychemistry.com/Type_substance_Canvas.html

Nomenclature Summary

Type of Compound	**General Formula**	**Examples**	**General Name**	**Examples**
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b AlF_3	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
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Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

AlF_3

- Metal-nonmetal (M_aA_b) so binary ionic
- Al only one charge – just name of metal with no Roman numeral.
  - Metals without Roman numerals –Groups 1, 2, 3, and Al, Zn, Cd, and Ag
- The cation name is aluminum.
- Monatomic anion names – (root)ide
- Name of the anion is fluoride.
- **Aluminum fluoride**

Nomenclature Summary

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Binary covalent	A_aB_b PF_3	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

PF_3

- Nonmetal-nonmetal (A_aB_b) so binary covalent.
- (prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide
- Leave off mono on first part of name.
- We use the prefix tri- to show three fluorine atoms.
- The root of the name fluorine is fluor-
- **Phosphorus trifluoride**

Nomenclature Summary

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Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
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Oxyacid	$H_aX_bO_c$ H_3PO_4	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

H_3PO_4

- Form of oxyacid, $H_aX_bO_c$
- (root)ic acid
- Use “phosphor” as the root in acid names.
- H_3PO_4 is **phosphoric acid.**

Nomenclature Summary

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Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion $CaCO_3$	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
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Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

$CaCO_3$

Periodic Table

Ca^{2+} named calcium

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1											1 H							2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

$CaCO_3$

Ion	Name	Ion	Name
NH_4^+	ammonium	NO_3^-	nitrate
OH^-	hydroxide	SO_4^{2-}	sulfate
CO_3^{2-}	carbonate	$C_2H_3O_2^-$	acetate
PO_4^{3-}	phosphate		

$CaCO_3$

- Metal polyatomic ion (M_aX_b) with X representing a polyatomic ion
- Ca is in Group 2, so the cation name is just the name of the metal.
- Need to memorize polyatomic names and formulas.
- $CaCO_3$ is **calcium carbonate.**

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Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s) $Ca(HSO_4)_2$	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

$Ca(HSO_4)_2$

- The name for the cation is calcium.
- Memorize SO_4^{2-} as sulfate.
- When a polyatomic anion with a charge of -2 has an H^+ added, we add “hydrogen” to the name of the anion.
- $Ca(HSO_4)_2$ is **calcium hydrogen sulfate.**

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b $CuCl_2$	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

$CuCl_2$

- Metal-nonmetal (M_aA_b) so binary ionic
- Cu is not on the list of metals without a Roman numeral, so we need a Roman numeral to show the charge.
- Cl is in group 17, so it is -1.
- Two Cl^- ions would be -2.
- Cu must be +2 to balance the charge, so the name of the cation is copper(II).
- Monatomic anions are named (root)ide, so Cl^- is chloride.
- $CuCl_2$ is **copper(II) chloride.**

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion NH_4F	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

NH_4F

- Polyatomic ion-nonmetal so ionic with a polyatomic ion.
- Memorize NH_4^+ as ammonium.
- Monatomic anions are named (root)ide.
- NH_4F is **ammonium fluoride.**

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion HCl(*aq*)	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

HCl(*aq*)

- HX(aq) is the form of a binary acid.
- Named hydro(root)ic acid
- HCl(*aq*) is **hydrochloric acid.**

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s) $(NH_4)_3PO_4$	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

$(NH_4)_3PO_4$

- Two polyatomic ions so ionic with polyatomic ions.
- Need to memorize names and formulas for polyatomic ions.
- $(NH_4)_3PO_4$ is **ammonium phosphate.**

Nomenclature Summary

Type of Compound	**General Formula**	**Examples**	**General Name**	**Examples**
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion Ammonium nitrate	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

Steps for Ionic Formulas

- The steps for writing formulas for ionic compounds are
  - Determine the formula, including charge, for the ions.
  - Determine the ratio of the ions necessary to balance the charge.

ammonium nitrate

- Ammonium and nitrate are both polyatomic ions.
- The memorized formula for ammonium is NH_4^+.
- The memorized formula for nitrate is NO_3^-.
- A 1:1 ratio balances the charge.
- Ammonium nitrate is **NH_4NO_3.** (Note no parentheses)

acetic acid

- It is probably best to memorize acetic acid as $HC_2H_3O_2$. It is also described at CH_3CO_2H.
- $C_2H_3O_2^-$ is acetate.
- If you add enough H^+ ions to the –ate anion to neutralize the charge, you get the –ic acid.
- Acetic acid is $\mathbf{HC_2H_3O_2}$.

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

sodium hydrogen sulfate

sodium hydrogen sulfate

Periodic Table

sodium ion – Na^+

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

sodium hydrogen sulfate

- “(name of metal) (name of polyatomic ion)" so ionic with a polyatomic ion.
- Sodium is in group 1, so it is +1.
- Sulfate is SO_4^{2-}.
- Assume one H^+.
- Adding one H^+ to SO_4^{2-} yields HSO_4^-.
- Balance the charge.
- **$NaHSO_4$**

Nomenclature Summary

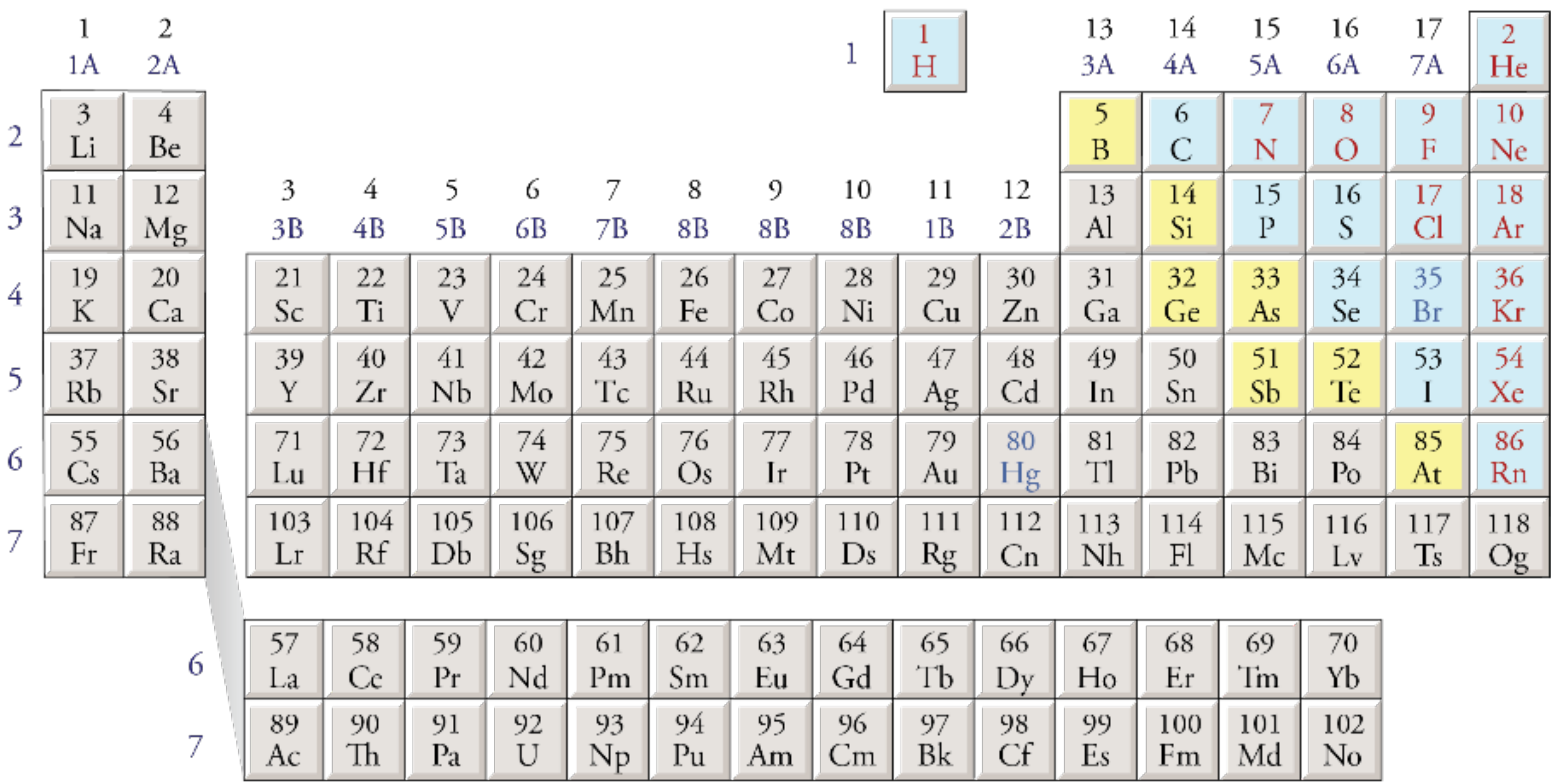
Type of Compound	**General Formula**	**Examples**	**General Name**	**Examples**
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b potassium	NaCl or $FeCl_3$ bromide	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

potassium bromide

Periodic Table

potassium – K^+

bromide – Br^-



potassium bromide

- “(name of metal) (root of nonmetal)ide” so binary ionic.
- K (for potassium) is in group 1, so the cation is K^+.
- Br (for bromine) is in group 17, so the anion is Br^-.
- One K^+ balances the charge on one Br^-.
- Potassium bromide is **KBr**

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

magnesium dihydrogen phosphate

magnesium dihydrogen phosphate

Periodic Table

magnesium – Mg^{2+}

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
										1	1 H							2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

magnesium dihydrogen phosphate

- “(name of metal) (name of polyatomic ion)" so ionic with a polyatomic ion.
- Magnesium is in group 2, so it is +2.
- Phosphate is PO_4^{3-}.
- Adding two H^+ ions to PO_4^{3-} yields $H_2PO_4^-$.
- Balance the charge.
- $\mathbf{Mg(H_2PO_4)_2}$

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

hydrofluoric acid

hydrofluoric acid

- “hydro(root)ic acid” so binary acid.
- Formulas for binary acids have the form HX(aq) or H_2X(aq).
- Fluorine atoms only form one bond.
- Hydrofluoric acid is **HF(aq)**.

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

diphosphorus tetroxide

diphosphorus tetroxide

- “(prefix)(name of first element in formula) (prefix)(root of second element)ide” so binary covalent.
- di- represents 2.
- Phosphorus is P
- tetra- represents 4.
- ox- is O.
- Diphosphorus tetroxide is $\mathbf{P_2O_4}$.

Nomenclature Summary

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

aluminum carbonate

aluminum carbonate

Periodic Table

aluminum – Al^{3+}

	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

aluminum carbonate

- “(name of metal) (name of polyatomic ion)” so ionic with a polyatomic ion.
- Aluminum is Al. It forms Al^{3+} ions.
- Memorize carbonate as CO_3^{2-}.
- Cross the superscripts to get the subscripts for Al^{3+} and CO_3^{2-}.
- **$Al_2(CO_3)_3$**

Nomenclature Summary

Type of Compound	**General Formula**	**Examples**	**General Name**	**Examples**
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula)(prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	NaCl or $FeCl_3$	(name of metal) (root of nonmetal)ide **or** (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) **or** (name of metal)(Roman numeral) (name of polyatomic ion) **or** ammonium (root of nonmetal)ide **or** ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	HX(*aq*)	HCl(*aq*)	hydro(root)ic acid	hydrochloric acid
Oxyacid sulfuric acid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

sulfuric acid

- “(root)ic acid” without “hydro-” so oxyacid.
- Sulfate is SO_4^{2-}.
- Add enough H^+ ions to neutralize charge.
- Sulfuric acid is $\mathbf{H_2SO_4}$.

Practice

- There are two tools on the textbook website that will allow you to practice the tasks described in this lesson.
  - Identification of types of substances

https://preparatorychemistry.com/Type_substance_Canvas.html

  - Converting between names and formulas for compounds

https://preparatorychemistry.com/nomenclature_Canvas.html

Arrhenius Base Definitions

- A ***base*** is a substance that generates OH^- when added to water.
- A ***basic*** solution is a solution with a significant concentration of OH^- ions.

Characteristics of Bases

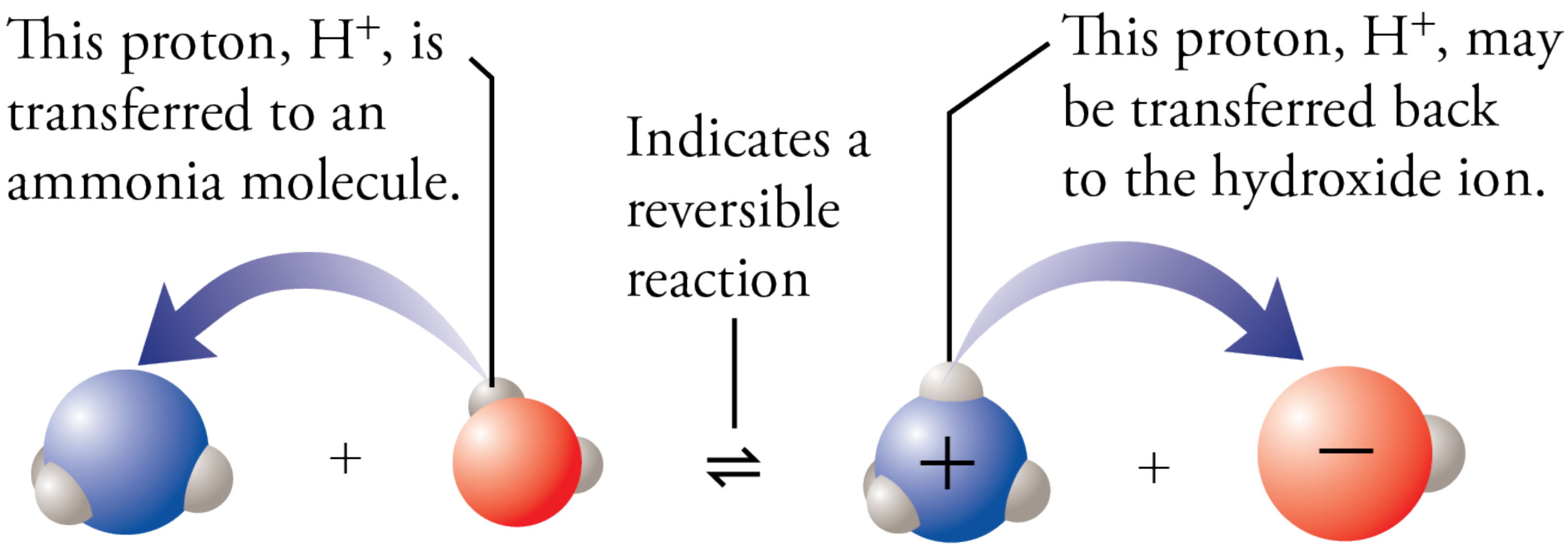
- Bases have a bitter taste.
- Bases feel slippery on your fingers.
- Bases turn litmus from red to blue.
- Bases react with acids.

Strong Bases

- ***Strong Base*** = due to a completion reaction with water, generates close to one (or more) OH^- for each formula unit of base added to water.
  - Metal hydroxides are strong bases.

Ammonia and Water

Ammonia reacts with water in a reversible reaction, which forms ammonium and hydroxide ions.

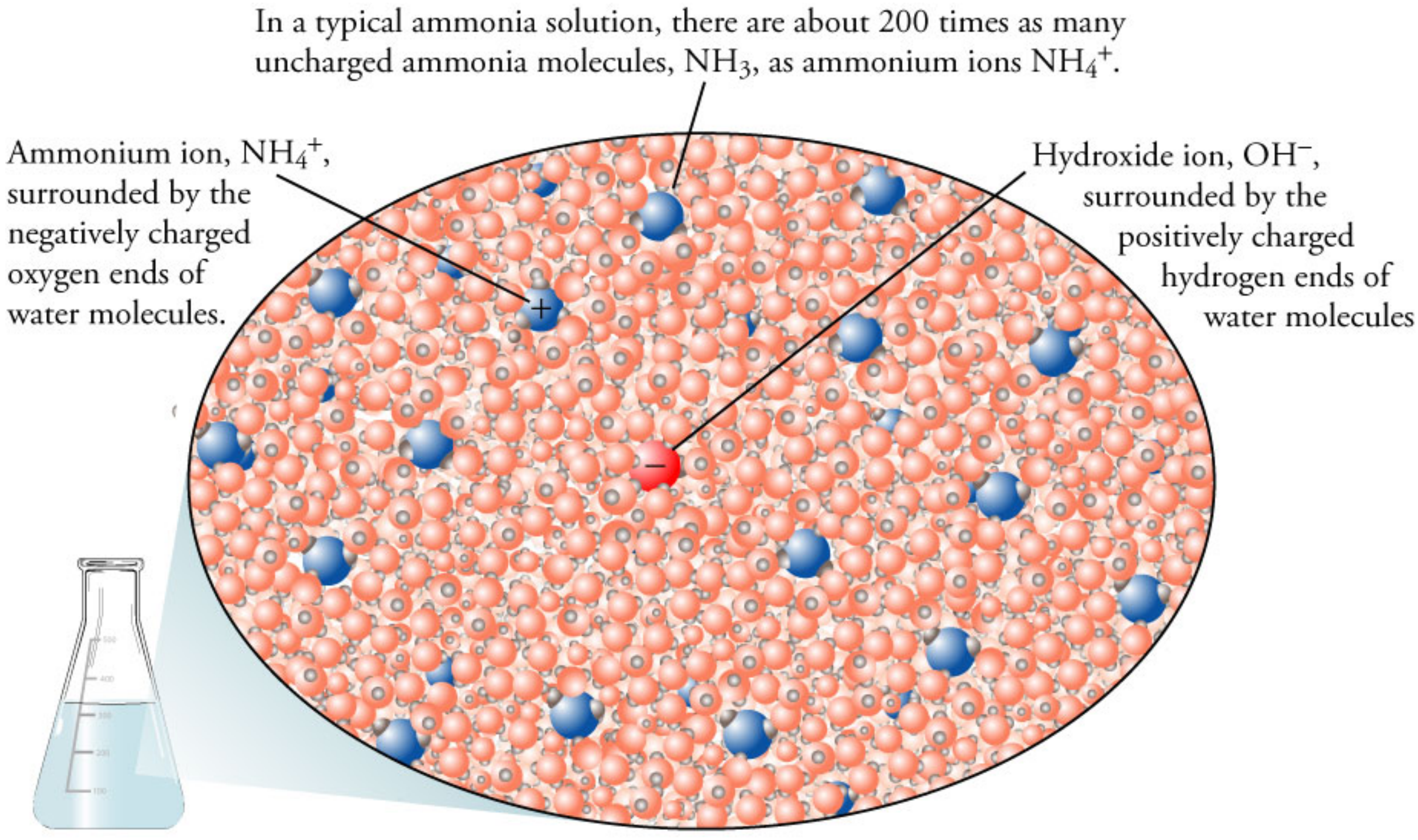


$$NH_3(aq) \quad + \quad H_2O(l) \quad \rightleftharpoons \quad NH_4^+(aq) \quad + \quad OH^-(aq)$$

Weak Base

- ***Weak Base*** = due to a reversible reaction with water, generates significantly less than one OH^- for each formula unit of base added to water.
  - Ammonia and ionic compounds that contain CO_3^{2-} or HCO_3^- are weak bases.

Ammonia Solution



Carbonate Bases

$Na_2CO_3(s) \rightarrow 2Na^+(aq) + CO_3^{2-}(aq)$

$CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + OH^-(aq)$

$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$

$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

Arrhenius Bases

	Strong	**Weak**
Ionic Compounds	Metal hydroxides	Ionic compounds with CO_3^{2-} and HCO_3^-
Certain Uncharged molecules	None	NH_3

Acidic and Basic Solutions

- The pH scale describes the acidity and basicity of dilute acid and base solutions.
- In pure water, there are proton transfers between water molecules that form hydronium ions and hydroxide ions.

$$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

- The reaction is reversible, and at equilibrium, the product of the hydronium ion and hydroxide ion concentrations expressed in mol/L is about 10^{-14}.

$$[H_3O^+][OH^-] = 10^{-14}$$

$[H_3O^+][OH^-] = 10^{-14}$

- We consider acidic and basic solutions to be dilute if they have a concentrations of 1 mol/L or less.
- Because the product of the concentrations of H_3O^+ and OH^- is 10^{-14}, as the concentration of H_3O^+ decreases from 1 mol/L to 10^{-14} mol/L, the concentration of OH^- increases from 10^{-14} mol/L to 1 mol/L.
- See the table at the right.

$[H_3O^+]$ (mol/L)	$[OH^-]$ (mol/L)
1	10^{-14}
10^{-1}	10^{-13}
10^{-2}	10^{-12}
10^{-3}	10^{-11}
10^{-4}	10^{-10}
10^{-5}	10^{-9}
10^{-6}	10^{-8}
10^{-7}	10^{-7}
10^{-8}	10^{-6}
10^{-9}	10^{-5}
10^{-10}	10^{-4}
10^{-11}	10^{-3}
10^{-12}	10^{-2}
10^{-13}	10^{-1}
10^{-14}	1

$$[H_3O^+][OH^-] = 10^{-14}$$

- When the H_3O^+ concentration is greater than the OH^- concentration, the solution is acidic. (Note that even in a dilute solution of acid, there are some hydroxide ions.)
- When the OH^- concentration is greater than the H_3O^+ concentration, the solution is basic.
- When the concentrations are equal, both 10^{-7} mol/L, we say the solution is neutral in the acid/base sense.

$[H_3O^+]$ (mol/L)	$[OH^-]$ (mol/L)
1	10^{-14}
10^{-1}	10^{-13}
10^{-2}	10^{-12}
10^{-3}	10^{-11}
10^{-4}	10^{-10}
10^{-5}	10^{-9}
10^{-6}	10^{-8}
10^{-7}	10^{-7}
10^{-8}	10^{-6}
10^{-9}	10^{-5}
10^{-10}	10^{-4}
10^{-11}	10^{-3}
10^{-12}	10^{-2}
10^{-13}	10^{-1}
10^{-14}	1

pH

- To avoid the small numbers associated with describing acidic and basic solutions in terms of mol/L, pH is defined as

  $$pH = -\log[H_3O^+]$$

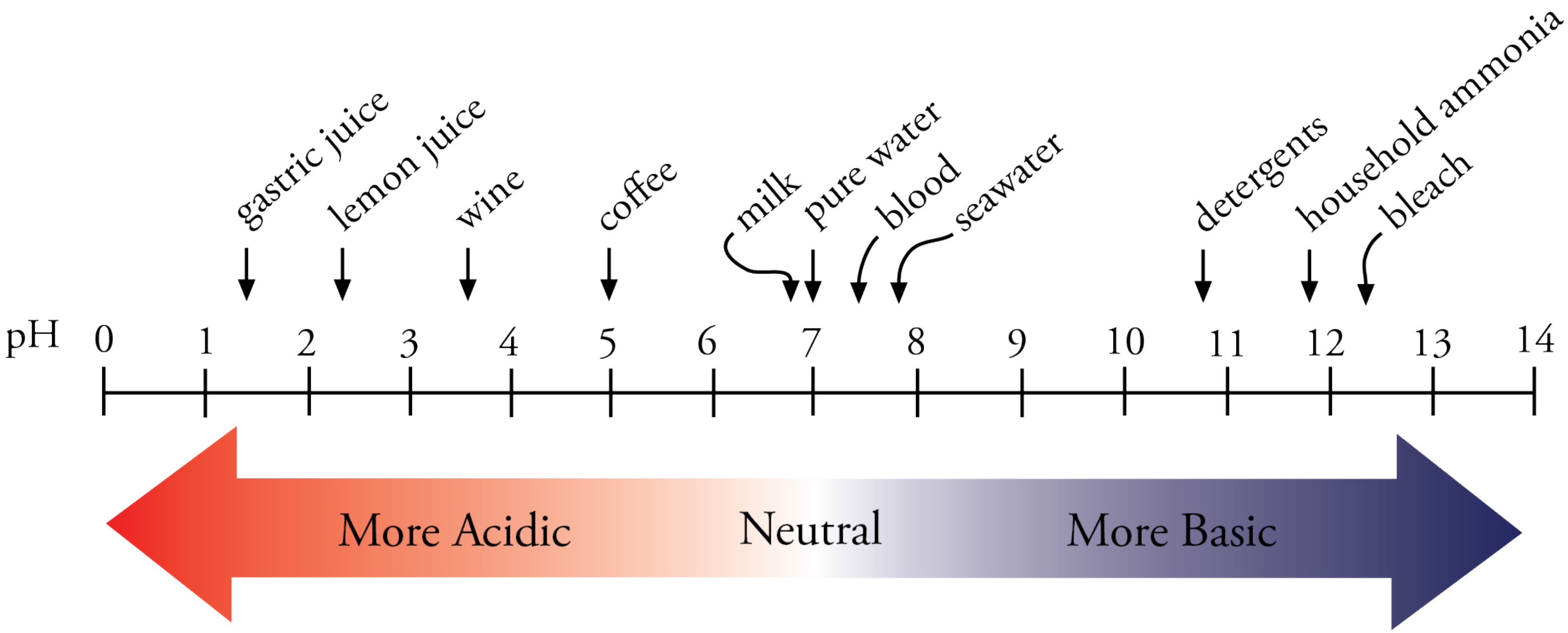
- An acidic solution that has an H_3O^+ concentration of 10^{-3} mol/L has a pH of 3 ($-\log 10^{-3} = 3$).
- A basic solution that has an OH^- concentration of 10^{-3} mol/L, and therefore an H_3O^+ concentration of 10^{-11} mol/L, has a pH of 11 ($-\log 10^{-11} = 11$).

$[H_3O^+][OH^-] = 10^{-14}$

- Dilute acidic solutions with H_3O^+ concentrations of 1 to 10^{-6} mol/L have a pHs of 0 to 6.
- Dilute basic solutions with OH^- concentrations of 10^{-6} to 1 mol/L have H_3O^+ concentrations of 10^{-8} to 10^{-14} mol/L and pHs of 8-14.
- Neutral solutions with H_3O^+ and OH^- concentrations 10^{-7} mol/L have a pH of 7.

$[H_3O^+]$ (mol/L)	$[OH^-]$ (mol/L)	pH
1	10^{-14}	0
10^{-1}	10^{-13}	1
10^{-2}	10^{-12}	2
10^{-3}	10^{-11}	3
10^{-4}	10^{-10}	4
10^{-5}	10^{-9}	5
10^{-6}	10^{-8}	6
10^{-7}	10^{-7}	7
10^{-8}	10^{-6}	8
10^{-9}	10^{-5}	9
10^{-10}	10^{-4}	10
10^{-11}	10^{-3}	11
10^{-12}	10^{-2}	12
10^{-13}	10^{-1}	13
10^{-14}	1	14

pH Range



Acidic solutions have pH values less than 7.

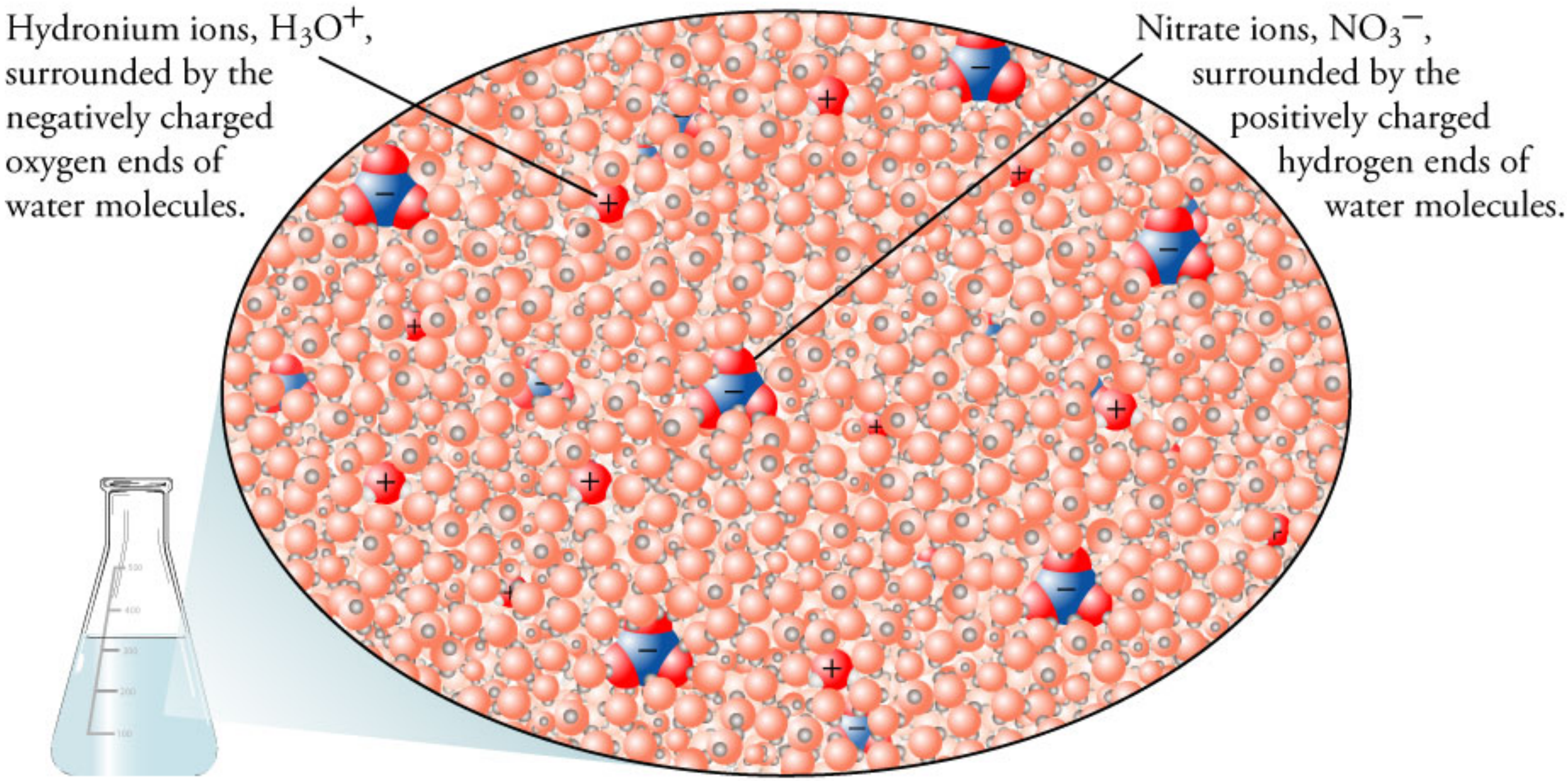
Basic solutions have pH values greater than 7.

Neutralization Reactions

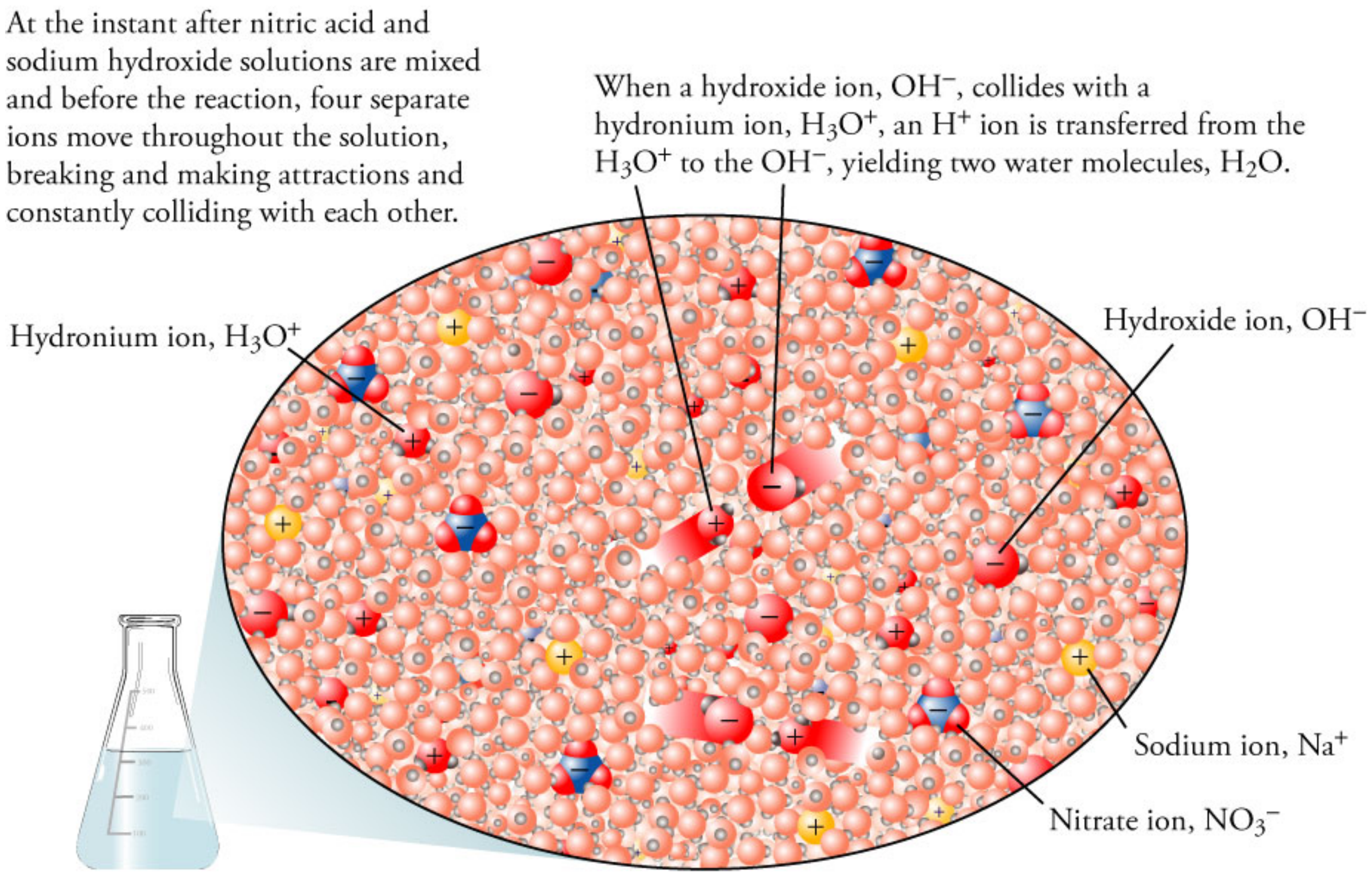
- Reactions between Arrhenius acids and Arrhenius bases are called ***neutralization reactions***.

$$HNO_3(aq) + NaOH(aq) \rightarrow H_2O(l) + NaNO_3(aq)$$

Aqueous Nitric Acid



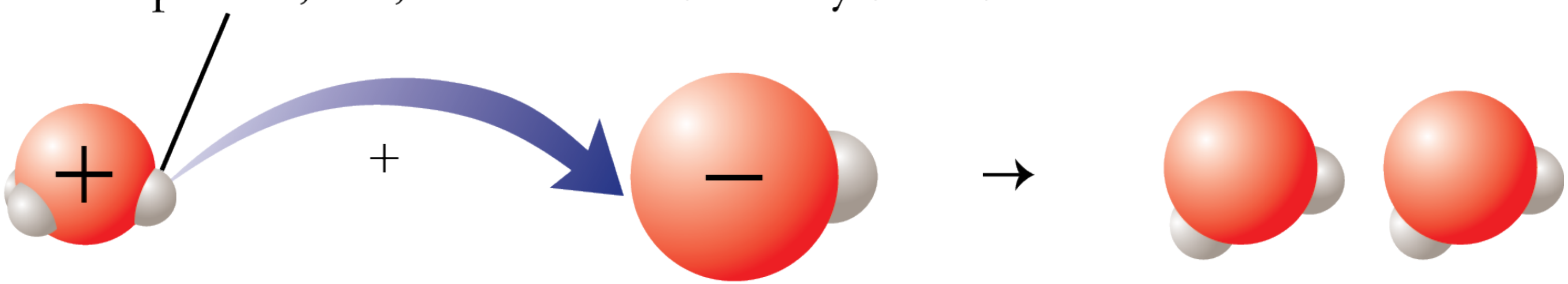
Mixture of HNO_3 and NaOH Before Reaction



Strong Acid and Strong Base Reaction

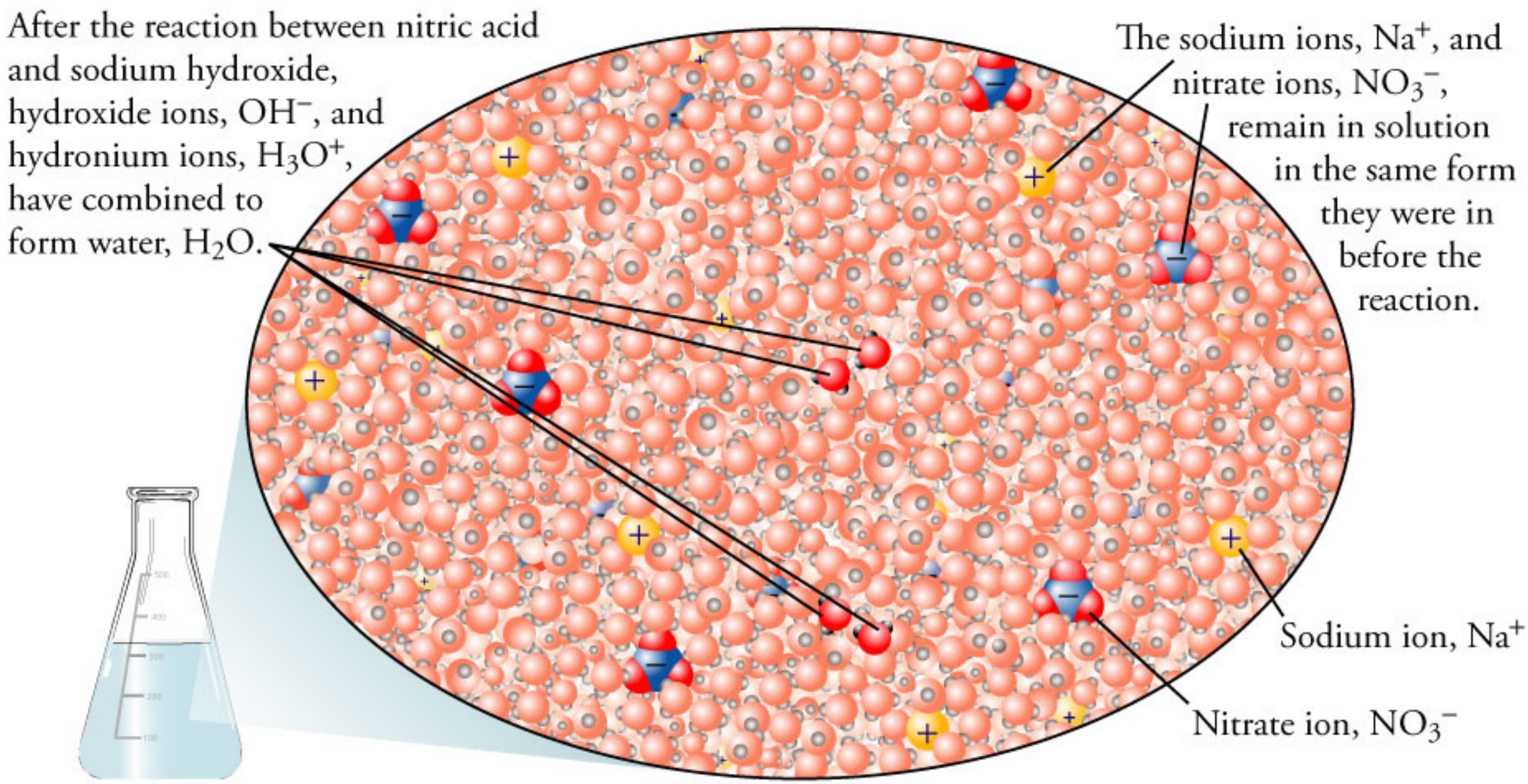
The hydronium ion, H_3O^+, from the strong acid reacts with the hydroxide ion, OH^-, from the strong base to form water, H_2O.

This proton, H^+, is transferred to a hydroxide ion.



$$H_3O^+(aq) \quad + \quad OH^-(aq) \quad \rightarrow \quad 2H_2O(l)$$

Mixture of HNO_3 and NaOH After the Reaction



https://preparatorychemistry.com/neutralization_Canvas.html

Reaction between an Acid and a Hydroxide Base.

- If you have an Arrhenius acid combined with an Arrhenius base, they will react in an acid-base reaction.
- The reactions we will see have the double displacement form.

$$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CB(aq)$$

  – The positive part of the acid is H^+.
- The hydroxide base can be soluble or insoluble.
- The products are water and a water-soluble ionic compound.

Reaction between an Acid and a Carbonate Base

- The reaction of an acid with a base containing the carbonate ion or the hydrogen carbonate ion has the double displacement form.

$$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CO_2(g) + CB(aq)$$

  – The positive part of the acid is H^+.
- The products are water, carbon dioxide, and a water-soluble ionic compound. The H_2O and the CO_2 come from the decomposition of the initial product H_2CO_3.

Steps for Writing Acid-Base Equations

- Write the formulas for the given reactants separate by a “+” and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.

$$AB(aq) + CD(aq \text{ or } s) \rightarrow$$

Steps for Writing Acid-Base Equations

- Follow these steps to determine the formulas for the products.
  - Divide the acid formula into H^+ and whatever is left after all of the H^+ ions are removed. For example, HNO_3 is divided into H^+ and NO_3^-, and H_2SO_4 is divided into H^+ and SO_4^{2-}.
  - Divide the base into its cation and whatever is left when the cations are removed. For example, NaOH is divided into Na^+ and OH^-, and K_2CO_3 is divided into K^+ and CO_3^{2-}.

Steps for Writing Acid-Base Equations (cont.)

- Follow these steps to determine the formulas for the products. (cont.)
  - If the base includes the hydroxide ion, the first product will be water.

    $$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CB(aq)$$

  - If the base includes either the carbonate ion or the hydrogen carbonate ion, the first products will be water and carbon dioxide.

    $$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CO_2(g) + CB(aq)$$

Steps for Writing Acid-Base Equations (cont.)

- Follow these steps to determine the formulas for the products. (cont.)
  - The formula for the second product is formed by combining the cation from the base and the anion from the acid. For example, Na^+ combines with NO_3^- to form the CB formula, $NaNO_3(aq)$. (Remember that even though the ions in ionic compounds dissolved in water are separated from each other, we describe them as together in the complete equation.)

$$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CB(aq)$$

or $$AB(aq) + CD(aq\ or\ s) \rightarrow H_2O(l) + CO_2(g) + CB(aq)$$

Example 1

- Write the complete equation for the neutralization reaction that takes place when aqueous solutions of sulfuric acid, H_2SO_4, and sodium hydroxide, NaOH, are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic hydroxide ions.)

Example 1
Steps

- The acid-base reactions we will see are double displacement reactions.

  AB + CD $\rightarrow$ AD + CB

- Write the formulas for the given reactants separated by a "+" and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.

  $H_2SO_4(aq) + NaOH(aq) \rightarrow$

Example 1
Steps

$$H_2SO_4(aq) + NaOH(aq) \rightarrow$$

- Identify A, B, C, and D.
  - For the acid H_2SO_4, A is H^+ and B is SO_4^{2-}.
  - For NaOH, C is Na^+ and D is OH^-.
- Write the formulas for the AD and CB products on the right side of the arrow. Remember to balance the charges when writing the formulas. H_2O will be followed by (l), and the ionic product will be followed by (aq).

$$H_2SO_4(aq) + NaOH(aq) \rightarrow H_2O(l) + Na_2SO_4(aq)$$

Example 1
Steps

$$H_2SO_4(aq) + NaOH(aq) \rightarrow H_2O(l) + Na_2SO_4(aq)$$

- If one of your products is H_2CO_3, eliminate it and write $H_2O(l)$ and $CO_2(g)$ in its place.
- Balance the equation.

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2H_2O(l) + Na_2SO_4(aq)$$

Example 2

- Write the complete equation for the neutralization reaction that takes place when aqueous solutions of hydrochloric acid, HCl(aq), and potassium carbonate, K_2CO_3, are mixed. (If an acid has more than one acidic hydrogen, assume that there is enough base to remove all of them. Assume that there is enough acid to neutralize all of the basic anions.)

Example 2
Steps

- The acid-base reactions we will see are double displacement reactions.

$$AB + CD \rightarrow AD + CB$$

- Write the formulas for the given reactants separate by a "+" and followed by a single arrow. The acid formula will be followed by an (aq), and the base formula will followed by (aq) if it is water soluble or (s) if it is insoluble.

$$HCl(aq) + K_2CO_3(aq) \rightarrow$$

Example 2
Steps

$HCl(aq) + K_2CO_3(aq) \rightarrow$

- Identify A, B, C, and D.
  - For the acid HCl, A is H^+ and B is Cl^-.
  - For K_2CO_3, C is K^+ and D is CO_3^{2-}.
- Write the formulas for the AD and CB products on the right side of the arrow. Remember to balance the charges when writing the formulas. The ionic product will be followed by (aq).

$HCl(aq) + K_2CO_3(aq) \rightarrow H_2CO_3(l) + KCl(aq)$

Example 2
Steps

$HCl(aq) + K_2CO_3(aq) \rightarrow H_2CO_3(aq) + KCl(aq)$

- If one of your products is H_2CO_3, eliminate it and write $H_2O(l)$ and $CO_2(g)$ in its place.

$$HCl(aq) + K_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g) + KCl(aq)$$

- Balance the equation.

$$2HCl(aq) + K_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g) + 2KCl(aq)$$

Three Definitions of Acids and Bases

- **Arrhenius**
  - An acid is a substance that generates H_3O^+ in water
  - A base is a substance that generates OH^- in water
- **Brønsted-Lowry**
- **Lewis**

Arrhenius Acid-Base Reactions?

$NH_3(aq) + HF(aq) \rightleftharpoons NH_4^+(aq) + F^-(aq)$
base acid

$H_2O(l) + HF(aq) \rightleftharpoons H_3O^+(aq) + F^-(aq)$
neutral acid

$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
base neutral

Acid and Base Definitions

- **Acid**
  - Arrhenius: a substance that generates H_3O^+ in water
  - Brønsted-Lowry: a proton, H^+, donor
- **Base**
  - Arrhenius: a substance that generates OH^- in water
  - Brønsted-Lowry: a proton, H^+, acceptor
- **Acid-Base Reaction**
  - Arrhenius: between an Arrhenius acid and base
  - Brønsted-Lowry: a proton (H^+) transfer

Brønsted-Lowry Acids and Bases

$NH_3(aq) + HF(aq) \rightleftharpoons NH_4^+(aq) + F^-(aq)$
base acid

$H_2O(l) + HF(aq) \rightleftharpoons H_3O^+(aq) + F^-(aq)$
base acid

$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
base acid

Why Two Definitions for Acids and Bases? (1)

- Positive Aspects of Arrhenius Definitions
  - All isolated substances can be classified as acids (generate H_3O^+ in water), bases (generate OH^- in water), or neither.
  - Allows predictions, including (1) whether substances will react with a base or acid, (2) whether the pH of a solution of the substance will be less than 7 or greater than 7, and (3) whether a solution of the substance will be sour or bitter.
- Negative Aspects of Arrhenius Definitions
  - Does not include similar reactions (H^+ transfer reactions) as acid-base reactions.

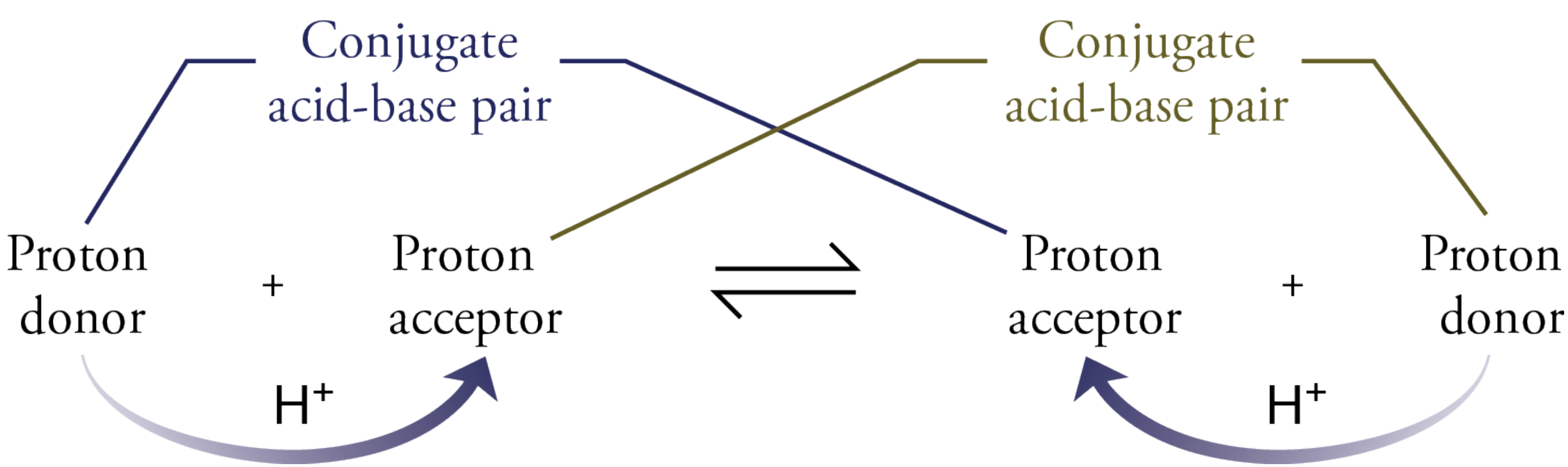
Why Two Definitions for Acids and Bases? (2)

- Positive aspects of Brønsted-Lowry model
  - Includes similar reactions (H^+ transfer reactions) as acid-base reactions.
- Negative aspects of Brønsted-Lowry model
  - Cannot classify isolated substances as acids, bases, or neither. The same substance can sometimes be an acid and sometimes a base.
  - Does not allow predictions of (1) whether substances will react with another substance, (2) whether the pH of a solution of the substance will be less than 7 or greater than 7, and (3) whether a solution will be sour or bitter.

Conjugate Acid-Base Pairs

$$\mathrm{NH_3}(aq) + \mathrm{HF}(aq) \rightleftharpoons \mathrm{NH_4^+}(aq) + \mathrm{F^-}(aq)$$

base acid acid base



Brønsted-Lowry Acids and Bases

$$H_2PO_4^-(aq) + HF(aq) \rightleftharpoons H_3PO_4(aq) + F^-(aq)$$

base acid acid base

- H_3PO_4 is the conjugate acid of $H_2PO_4^-$.
- $H_2PO_4^-$ is the conjugate base of H_3PO_4.
- H_3PO_4 and $H_2PO_4^-$ are a conjugate acid-base pair.
- F^- is the conjugate base of the acid HF.
- HF is the conjugate acid of the acid F^-.
- HF and F^- are a conjugate acid-base pair.

Amphoteric Substances

Can be a Brønsted-Lowry acid in one reaction and a Brønsted-Lowry base in another?

$HCO_3^-(aq) + HF(aq) \rightleftharpoons CO_2(g) + H_2O(l) + F^-(aq)$

base acid

$HCO_3^-(aq) + OH^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H_2O(l)$

acid base

$H_2PO_4^-(aq) + HF(aq) \rightleftharpoons H_3PO_4(aq) + F^-(aq)$

base acid

$H_2PO_4^-(aq) + 2OH^-(aq) \rightarrow PO_4^{3-}(aq) + 2H_2O(l)$

acid base