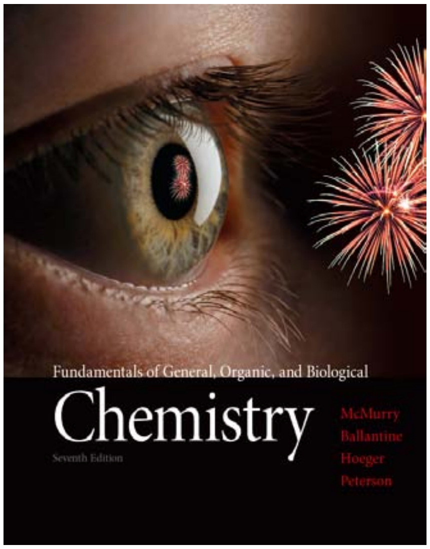
Chapter 3 Lecture



Fundamentals of General, Organic, and Biological Chemistry

7th Edition

McMurry, Ballantine, Hoeger, Peterson

Chapter Three

Ionic Compounds

Julie Klare
Gwinnett Technical College

Outline

Goals

1. **What is an ion, what is an ionic bond, and what are the general characteristics of ionic compounds?**

   Be able to describe ions and ionic bonds, and give the general properties of compounds that contain ionic bonds.

2. **What is the octet rule, and how does it apply to ions?**

   Be able to state the octet rule and use it to predict the electron configurations of ions of main group elements.

3. **What is the relationship between an element's position in the periodic table and the formation of its ion?**

   Be able to predict what ions are likely to be formed by atoms of a given element.

Goals, *Continued*

4. **What determines the chemical formula of an ionic compound?**

   Be able to write formulas for ionic compounds, given the identities of the ions.

5. **How are ionic compounds named?**

   Be able to name an ionic compound from its formula or give the formula of a compound from its name.

6. **What are acids and bases?**

   Be able to recognize common acids and bases.

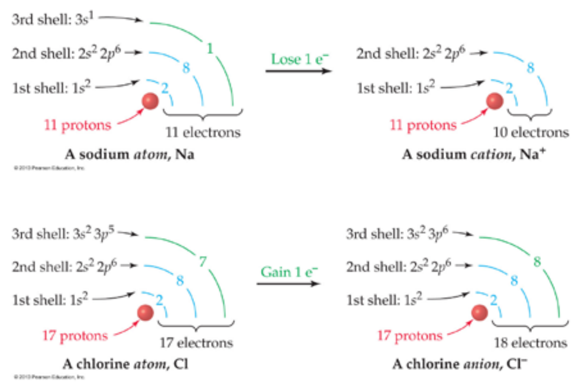
3.1 Ions

- Metals tend to form compounds with nonmetals.
- Alkali metals (group IA) react with halogens (group 7A) to make a variety of compounds with similar properties.
  - The two elements are always found in a 1:1 ratio.
  - The compounds have melting points over 500 °C.
  - Each is a stable, white, crystalline solid.
  - Each is soluble in water.
  - The water solution of each compound conducts electricity.

3.1 Ions

- Electricity can only flow through a medium containing charged particles that are free to move.
- Atoms are electrically neutral because they contain equal numbers of protons and electrons.
- By gaining or losing electrons, an atom can be converted into a charged particle called an **ion.**
  - The loss of one or more electrons from a neutral atom gives a positively charged ion called a **cation**.
  - The gain of one or more electrons by a neutral atom gives a negatively charged ion called an **anion**.

3.1 Ions

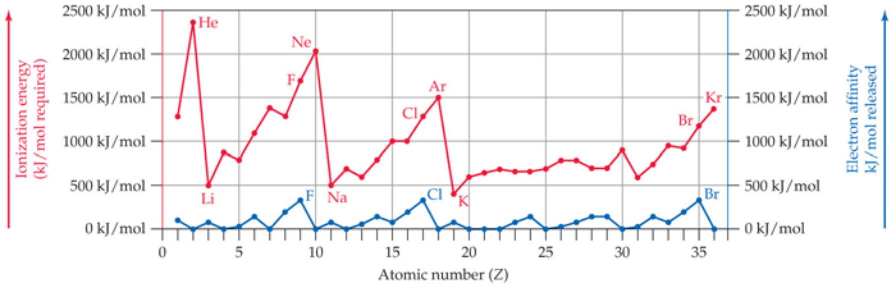


- The symbol for a cation is written by adding the positive charge as a superscript to the symbol for the element.
- An anion symbol is written by adding the negative charge as a superscript.
- If the charge is greater than 1, the number is used.

3.2 Periodic Properties and Ion Formation

- **Ionization energy** is the energy required to remove one electron from a single atom in the gaseous state.
  - Small values indicate ease of losing electrons to form cations.
- **Electron affinity** is the energy released on adding an electron to a single atom in the gaseous state.
  - Halogens have the largest values and gain electrons most easily.

3.2 Periodic Properties and Ion Formation



- Halogens gain electrons most easily.
- Alkali metals lose electrons most easily.
- Noble gases neither lose nor gain electrons.
- Elements near the middle of the periodic table do not form ions easily.

3.2 Periodic Properties and Ion Formation

- Elements that lose an electron, and those that gain an electron will react with each other by transfer of an electron.
- The product that results is electrically neutral.

(b)

3.3 Ionic Bonds

- Ion-transfer reactions of metals and nonmetals form products unlike either element.
- Because opposite electrical charges attract each other, the positive ion and negative ion are said to be held together by an **ionic bond**.
- There are many ions attracted by ionic bonds to their nearest neighbors. These crystals are **ionic solids**.
- Compounds of this type are referred to as **ionic compounds**.

3.4 Some Properties of Ionic Compounds

- Ions in each compound settle into a pattern that efficiently fills space and maximizes ionic bonding.
- Ions in an ionic solid are held rigidly in place by attraction to their neighbors.
- Once an ionic solid is dissolved in water, the ions can move freely, which accounts for the electrical conductivity of these compounds in solution.

3.4 Some Properties of Ionic Compounds

- Ionic compounds have very high melting and boiling points. Sodium chloride melts at 801 °C and boils at 1413 °C.
- Ionic solids shatter if struck sharply.
- Ionic compounds dissolve in water if the attraction between water and the ions overcomes the attraction of the ions for one another. Not all ionic compounds are water soluble.

3.4 Some Properties of Ionic Compounds

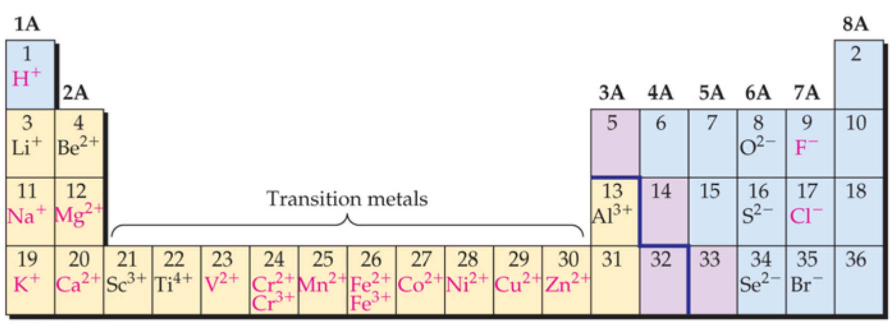
Ionic Liquids

- Ionic liquids have low melting points, high viscosity, low to moderate electrical conductivity, and low volatility.
- One of the first *room temperature ionic liquids* (or RTILs), ethylammonium nitrate, was synthesized in 1914 by Paul Walden.
- Most RTILs consist of a bulky, asymmetric organic cation, combined with a variety of anions.
- The bulky cations cannot pack together; they tend to form highly viscous liquids that exhibit low volatility.
- RTILs also provide unique solvent properties, enabling them to dissolve substances that are not very soluble in more conventional solvents. Low volatility also makes them environmentally friendly.
- RTILs can dissolve cellulose, facilitating its conversion into fermentable sugars.

3.5 Ions and the Octet Rule

- Alkali metals have a single valence electron and an electron configuration ns^1.
- Halogens have seven valence electrons and an electron configuration ns^2np^5.
- When halogens and alkali metals react, an electron is transferred, giving both ns^2np^6 configurations with eight valence electrons.
- This is a noble gas electron configuration.
- **Octet rule:** Main group elements tend to undergo reactions that leave them with eight valence electrons.

3.6 Ions of Some Common Elements



3.6 Ions of Some Common Elements

- Group 1A: M → M^{+} + e^{-}
- Group 2A: M → M^{2+} + $2e^{-}$
- Group 3A: Al → Al^{3+} + $3e^{-}$; no other common ions.
- Group 4A, 5A: no common ions.
- Group 6A: X + $2e^{-}$ → X^{2-}
- Group 7A: X + e^{-} → X^{-}
- Transition metals form cations, but can lose one or more *d* electrons in addition to losing valence *s* electrons. The octet rule is not followed.

3.6 Ions of Some Common Elements

Important Points about Ion Formation and the Periodic Table

- **Metals form cations by losing one or more electrons.**
  - Group 1A and 2A metals form +1 and +2 ions, respectively, to achieve a noble gas configuration.
  - Transition metals can form cations of more than one charge by losing a combination of valence-shell *s* electrons and inner-shell *d* electrons.
- **Reactive nonmetals form anions by gaining one or more electrons to achieve a noble gas configuration.**
  - Group 6A nonmetals oxygen and sulfur form the anions O^{2-} and S^{2-}.
  - Group 7A elements (the halogens) form –1 ions.
- **Group 8A elements (the noble gases) are unreactive.**
- **Ionic charges of main group elements can be predicted using the group number and the octet rule.**
  - For 1A and 2A metals, cation charge = group number.
  - For nonmetals in groups 5A, 6A, and 7A, anion charge = 8 – (group number).

© 2013 Pearson Education, Inc.

3.6 Ions of Some Common Elements

Salt

- The idea that high salt intake and high blood pressure go hand-in-hand is a highly-publicized piece of nutritional lore.
- Salt has been prized since the earliest recorded times as a seasoning, a food preservative, and a form of payment.
- Salt is perhaps the easiest of all minerals to obtain and purify. Most salt is obtained by mining the vast deposits of *halite*, or *rock salt*, formed by evaporation of ancient inland seas.
- Too much sodium has been linked to both hypertension and kidney ailments. The recommended daily intake (RDI) for sodium is 2300 mg. The average adult in most industrialized countries consumes over twice this amount.
- What should an individual do? The best answer, as in so many things, is to use moderation and common sense.

3.7 Naming Ions

- Main group metal cations in groups 1A, 2A, and 3A are named by identifying the metal, followed by the word "ion."
- Transition metals can form more than one type of cation. Two naming systems are used.
  - **Old System:** The ion with the smaller charge is given the ending -*ous* and the ion with the larger charge is given the ending -*ic*.
  - **New System:** The charge on the ion is given as a Roman numeral in parentheses right after the metal name.

3.7 Naming Ions

- Main group metal cations are named by identifying the metal, followed by the word "ion."
- Transition metals can form more than one type of cation. Two naming systems are used.
  - **Old:** The ion with the smaller charge is given the ending -*ous* and the ion with the larger charge is given the ending -*ic*.
  - **New:** The charge on the ion is given as a Roman numeral in parentheses right after the metal name.
- Anions are named by replacing the ending of the element name with -*ide*, followed by the word "ion."

3.8 Polyatomic Ions

- **Polyatomic ion** An ion that is composed of more than one atom.
- The atoms in a polyatomic ion are held together by covalent bonds.
- A polyatomic ion is charged because it contains a total number of electrons that is different from the total number of protons in the combined atoms.
- These ions are encountered so frequently that it is essential to memorize their names and formulas.

3.8 Polyatomic Ions

TABLE 3.3 Some Common Polyatomic Ions

Name	Formula	Name	Formula
Hydronium ion	H_3O^+	Nitrate ion	NO_3^-
Ammonium ion	NH_4^+	Nitrite ion	NO_2^-
Acetate ion	$CH_3CO_2^-$	Oxalate ion	$C_2O_4^{2-}$
Carbonate ion	CO_3^{2-}	Permanganate ion	MnO_4^-
Hydrogen carbonate ion (bicarbonate ion)	HCO_3^-	Phosphate ion	PO_4^{3-}
Chromate ion	CrO_4^{2-}	Hydrogen phosphate ion (biphosphate ion)	HPO_4^{2-}
Dichromate ion	$Cr_2O_7^{2-}$	Dihydrogen phosphate ion	$H_2PO_4^-$
Cyanide ion	CN^-	Sulfate ion	SO_4^{2-}
Hydroxide ion	OH^-	Hydrogen sulfate ion (bisulfate ion)	HSO_4^-
Hypochlorite ion	OCl^-	Sulfite ion	SO_3^{2-}

3.8 Polyatomic Ions

Some Biologically Important Ions

Ion	Location	Function	Dietary source
Ca^{2+}	Outside cell; 99% of Ca^{2+} is in bones and teeth as $Ca_3(PO_4)_2$ and $CaCO_3$	Bone and tooth structure; necessary for blood clotting, muscle contraction, and transmission of nerve impulses	Milk, whole grains, leafy vegetables
Fe^{2+}	Blood hemoglobin	Transports oxygen from lungs to cells	Liver, red meat, leafy green vegetables
K^+	Fluids inside cells	Maintain ion concentrations in cells; regulate insulin release and heartbeat	Milk, oranges, bananas, meat
Na^+	Fluids outside cells	Protect against fluid loss; necessary for muscle contraction and transmission of nerve impulses	Table salt, seafood
Mg^{2+}	Fluids inside cells; bone	Present in many enzymes; needed for energy generation and muscle contraction	Leafy green plants, seafood, nuts
Cl^-	Fluids outside cells; gastric juice	Maintain fluid balance in cells; help transfer CO_2 from blood to lungs	Table salt, seafood
HCO_3^-	Fluids outside cells	Control acid–base balance in blood	By-product of food metabolism
HPO_4^{2-}	Fluids inside cells; bones and teeth	Control acid–base balance in cells	Fish, poultry, milk

3.9 Formulas of Ionic Compounds

- All chemical compounds are neutral.
- Once the ions are identified, decide how many ions of each type give a total charge of zero.
- The chemical formula of an ionic compound tells the ratio of anions and cations.

3.9 Formulas of Ionic Compounds

- If the ions have the same charge, one of each is needed.

$$K^+ + F^- \rightarrow KF$$

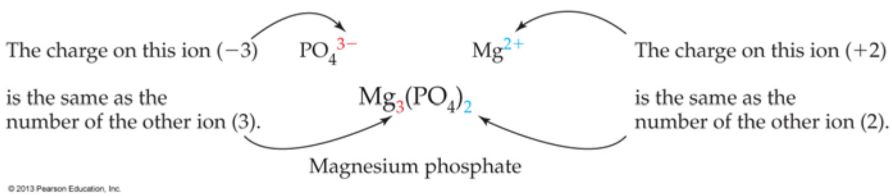
- If the ions have different charges, unequal numbers of anions and cations must combine to have a net charge of zero.

$$2\ K^+ + O^{2-} \rightarrow K_2O$$

$$Ca^{2+} + 2\ Cl^- \rightarrow CaCl_2$$

3.9 Formulas of Ionic Compounds

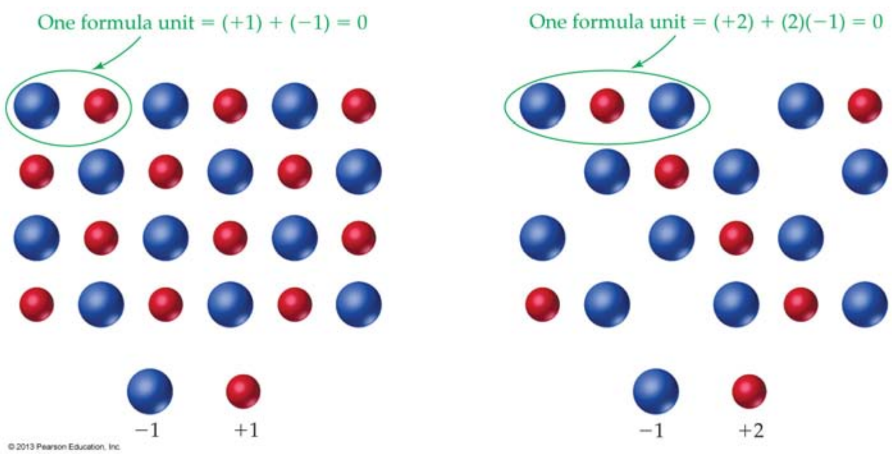
When the two ions have different charges, the number of one ion is equal to the charge on the other ion.



3.9 Formulas of Ionic Compounds

- The formula of an ionic compound shows the lowest possible ratio of atoms and is known as a *simplest formula*.
- There is no such thing as a single neutral *particle* of an ionic compound.
- **Formula unit** The formula that identifies the smallest neutral unit of an ionic compound.

3.9 Formulas of Ionic Compounds



3.9 Formulas of Ionic Compounds

Once the numbers and kinds of ions in a compound are known, the formula is written using the following rules:

- List the cation first and the anion second.
- Do not write the charges of the ions.
- Use parentheses around a polyatomic ion formula if it has a subscript.

3.10 Naming Ionic Compounds

- These compounds are named by citing first the cation and then the anion, with a space between words.
- There are two kinds of ionic compounds:
  - **Type I** ionic compounds contain cations of main group elements.
  - **Type II** ionic compounds contain metals that can exhibit more than one charge.
- These require different naming conventions.

3.10 Naming Ionic Compounds

- **Type I** ionic compounds contain cations of main group elements.
  - The charges on these cations do not vary.
  - Do not specify the charge on the cation.

NaCl is sodium chloride

$MgCO_3$ is magnesium carbonate

3.10 Naming Ionic Compounds

- **Type II** ionic compounds contain metals that can exhibit more than one charge.
  - Specify the charge on the cation in these compounds with either the old (-*ous, -ic*) or the new (Roman numerals) system.

$FeCl_2$ is iron(II) chloride or ferrous chloride.

$FeCl_3$ is iron(III) chloride or ferric chloride.

3.10 Naming Ionic Compounds

- Do *not* name these compounds iron *di*chloride or iron *tri*chloride.
- Once the charge on the metal is known, the number of anions needed to yield a neutral compound is also known.
- Charges do not need to be included as part of the compound name.

3.10 Naming Ionic Compounds

TABLE 3.4 Some Common Ionic Compounds and Their Applications

Chemical Name (Common Name)	Formula	Applications
Ammonium carbonate	$(NH_4)_2CO_3$	Smelling salts
Calcium hydroxide (hydrated lime)	$Ca(OH)_2$	Mortar, plaster, whitewash
Calcium oxide (lime)	CaO	Lawn treatment, industrial chemical
Lithium carbonate ("lithium")	Li_2CO_3	Treatment of bipolar disorder
Magnesium hydroxide (milk of magnesia)	$Mg(OH)_2$	Antacid
Magnesium sulfate (Epsom salts)	$MgSO_4$	Laxative, anticonvulsant
Potassium permanganate	$KMnO_4$	Antiseptic, disinfectant*
Potassium nitrate (saltpeter)	KNO_3	Fireworks, matches, and desensitizer for teeth
Silver nitrate	$AgNO_3$	Antiseptic, germicide
Sodium bicarbonate (baking soda)	$NaHCO_3$	Baking powder, antacid, mouthwash, deodorizer
Sodium hypochlorite	$NaOCl$	Disinfectant; active ingredient in household bleach
Zinc oxide	ZnO	Skin protection, in calamine lotion

**Antiseptics and disinfectants can also be harmful/toxic to non-harmful microorganisms, but are used specifically to prevent infection from harmful microorganisms.*

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

- Two of the most important ions are the hydrogen cation (H^+) and the hydroxide anion (OH^-).
- A hydrogen cation is simply a proton.
- When an acid dissolves in water, the proton attaches to a molecule of water to form a hydronium ion.

$$H^+ + H_2O \rightarrow H_3O^+$$

- Chemists use hydrogen and hydronium ions interchangeably.

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

- A hydroxide anion is a polyatomic ion in which an oxygen atom is covalently bonded to a hydrogen atom.
- The importance of the H^+ cation and the OH^- anion is that they are fundamental to the concepts of *acids* and *bases.*
  - **Acid:** A substance that provides H^+ ions in water
  - **Base:** A substance that provides OH^- ions in water

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

TABLE 3.5 Some Common Acids and the Anions Derived from Them

Acids		Anions	
Acetic acid	CH_3COOH	Acetate ion	*CH_3COO^-
Carbonic acid	H_2CO_3	Hydrogen carbonate ion (bicarbonate ion) Carbonate ion	CO_3^{2-}
Hydrochloric acid	HCl	Chloride ion	Cl^-
Nitric acid	HNO_3	Nitrate ion	NO_3^-
Nitrous acid	HNO_2	Nitrite ion	NO_2^-
Phosphoric acid	H_3PO_4	Dihydrogen phosphate ion Hydrogen phosphate ion Phosphate ion	$H_2PO_4^-$ HPO_4^{2-} PO_4^{3-}
Sulfuric acid	H_2SO_4	Hydrogen sulfate ion Sulfate ion	HSO_4^- SO_4^{2-}

**Sometimes written* $C_2H_3O_2^-$ *or as* $CH_3CO_2^-$.

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

- Different acids can provide different numbers of H^+ ions per acid molecule.
  - Hydrochloric acid, HCl, provides one H^+ ion per acid molecule.
  - Sulfuric acid, H_2SO_4, can provide two H^+ ions per acid molecule.
  - Phosphoric acid, H_3PO_4, can provide three H^+ ions per acid molecule.

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

- Sodium hydroxide (NaOH) and potassium hydroxide (KOH) are bases.
- When these compounds dissolve, OH^- anions go into solution along with the metal cation.
- Different bases can provide different numbers of OH^- ions per formula unit.
  - Sodium hydroxide provides one OH^- ion per formula unit.
  - Barium hydroxide, $Ba(OH)_2$ can provide two OH^- ions per formula unit.

3.11 H^+ and OH^- Ions: An Introduction to Acids and Bases

Osteoporosis

- About 70% of bone is the *hydroxyapatite*, $Ca_{10}(PO_4)_6(OH)_2$, which provides hardness.
- The remaining 30% is the protein *collagen*, which provides flexibility and resistance to breakage.
- Bone mass increases from birth until the mid 30s, after which bone density decreases.
- This can lead to a clinical condition called *osteoporosis*, particularly common in postmenopausal women.
- Treatment includes *bisphosphonates* that bind to the calcium in bone.
- Treatment with sodium fluoride also shows considerable promise. Fluoride ion reacts with hydroxyapatite to give *fluorapatite*, increasing both bone strength and density.

Chapter Summary

1. What is an ion, what is an ionic bond, and what are the general characteristics of ionic compounds?

- Atoms are converted into *cations* by the loss of electrons and into *anions* by the gain of electrons.
- *Ionic bonds* result from the attraction between opposite electrical charges.
- *Ionic compounds* conduct electricity when dissolved, and generally are crystalline solids with high melting and boiling points.

Chapter Summary

2. What is the octet rule, and how does it apply to ions?

- A valence-shell electron configuration of eight electrons leads to stability and lack of reactivity, as typified by the noble gases.
- According to the *octet rule*, atoms of main group elements tend to form ions in which they have gained or lost the number of electrons to reach a noble gas configuration.

Chapter Summary

3. What is the relationship between an element's position in the periodic table and the formation of its ion?

- Periodic variations in *ionization energy* show that metals lose electrons more easily than nonmetals. As a result, metals usually form cations.
- Periodic variations in *electron affinity* show that nonmetals gain electrons more easily than metals. As a result, nonmetals usually form anions.
- Ionic charge can be predicted from group number and the octet rule.
  - Main group metal cation charges are equal to the group number.
  - Nonmetal anion charges are equal to (8 – group number).

Chapter Summary

4. What determines the chemical formula of an ionic compound?

- Ionic compounds contain appropriate numbers of anions and cations to maintain overall neutrality
- This provides a means of determining their chemical formulas.

Chapter Summary

5. How are ionic compounds named?

- Cations have the same name as the metal from which they are derived.
- Monatomic anions have the name ending -*ide*.
- For metals that form more than one ion, a Roman numeral equal to the charge on the ion is added to the name of the cation.
- Alternatively, the ending -*ous* is added to the name of the cation with the lesser charge and the ending -*ic* is added to the name of the cation with the greater charge.
- To name an ionic compound, the cation name is given first, with the charge of the metal ion indicated if necessary. The anion name is given second.

Chapter Summary

6. What are acids and bases?

- The hydrogen ion, H^+, and the hydroxide ion, OH^-, are among the most important ions in chemistry
- An *acid* is a substance that yields H^+ ions when dissolved in water.
- A *base* is a substance that yields OH^- ions when dissolved in water.