Chapter 15

Acids, Bases and Salts

15.1 Acids and bases

acid

derived from Latin *acidus* (meaning sour or tart)

related to Latin *acetum* (meaning vinegar)

characteristic properties associated with acid:

1. sour taste
2. change the color of litmus from blue to red
3. react with
   - metal (such as Zn, Mg) to produce H_2 gas
   - hydroxide base to produce H_2O and salt
   - carbonate to produce CO_2

H^+ released by acids in water solution

base

capable of liberating OH^- in water solution

LiOH, NaOH, KOH, $Ca(OH)_2$, $Ba(OH)_2$

characteristic properties associated with base:

1. bitter or caustic taste
2. a slippery, soapy feeling
3. the ability to change litmus from red to blue
4. the ability to interact with acids

1884 **Arrhenius acid-base**

an acid is a hydrogen-containing substance that dissociates to produce hydrogen ion, and a base is a hydroxide-containing substance that dissociates to produce hydroxide ion in aqueous solution

$HA \longrightarrow H^+(aq) + A^-(aq)$

acid

$MOH \longrightarrow M^+(aq) + OH^-(aq)$

base

an Arrhenius acid solution contains an excess of H^+ ions, an Arrhenius base solution contains an excess of OH^- ions

1923 **Brønsted-Lowry theory**

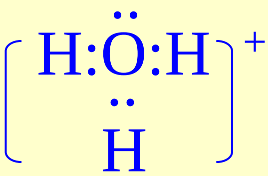
a Brønsted-Lowry acid is a proton (H^+) donor

a Brønsted-Lowry base is a proton (H^+) acceptor

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

HCl: acid H_2O: base

hydronium ion H_3O^+



conjugated acid and base

conjugated acid-base pair

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

conjugated acid-base pair

acid   base   base   acid

$NH_4^+ + H_2O \longrightarrow NH_3 + H_3O^+$

acid   base   base   acid

ex. 15.1 write the formula for

(a) the conjugated base of H_2O and of HNO_3

OH^- NO_3^-

(b) the conjugated acid of SO_4^{2-} and $C_2H_3O_2^-$

HSO_4^- $HC_2H_3O_2$

Lewis acid-base theory

a base is any substance that has an unshared pair of electrons **an electron-pair donor**

an acid is any substance that will attach itself to or a pair of electrons **an electron-pair acceptor**

ex.

$$\underset{\text{acid}}{H^+} + \underset{\text{base}}{:\overset{\displaystyle H}{\underset{\displaystyle H}{\ddot{\underset{\cdot\cdot}{N}}}}:H} \longrightarrow \left[H:\overset{\displaystyle H}{\underset{\displaystyle H}{\ddot{\underset{\cdot\cdot}{N}}}}:H \right]^+$$

$$F_3B + :NH_3 \longrightarrow F_3B—NH_3$$

summary

Table 15.1 Summary of Acid–Base Definitions

Theory	Acid	Base
Arrhenius	A hydrogen-containing substance that produces hydrogen ions in aqueous solution	A hydroxide-containing substance that produces hydroxide ions in aqueous solution
Brønsted–Lowry	A proton (H^+) donor	A proton (H^+) acceptor
Lewis	Any species that will bond to an unshared pair of electrons (electron-pair acceptor)	Any species that has an unshared pair of electrons (electron-pair donor)

15.2 Reactions of acids

1. reaction with metals

acid + metal $\longrightarrow$ hydrogen + ionic compound

$2\ HCl + Ca \longrightarrow H_2 + CaCl_2$

$H_2SO_4 + Mg \longrightarrow H_2 + MgSO_4$

$6\ HC_2H_3O_2 + 2\ Al \longrightarrow 3\ H_2 + 2\ Al(C_2H_3O_2)_3$

nitric acid HNO_3 is oxidizing agent, react with metals to produce water instead of H_2

$3\ Zn + 8\ HNO_3 \longrightarrow 3\ Zn(NO_3)_2 + 2\ NO + 4\ H_2O$

2. reaction with base

acid + base $\longrightarrow$ salt + water

$HBr + KOH \longrightarrow KBr + H_2O$

$2\ HNO_3 + Ca(OH)_2 \longrightarrow Ca(NO_3)_2 + 2\ H_2O$

$2\ H_3PO_4 + 3\ Ba(OH)_2 \longrightarrow Ba_3(PO_4)_2 + 6\ H_2O$

3. reaction with metal oxides

acid + metal oxide $\longrightarrow$ salt + water

$2\ HCl + Na_2O \longrightarrow 2\ NaCl + H_2O$

$H_2SO_4 + MgO \longrightarrow MgSO_4 + H_2O$

$6\ HCl + Fe_2O_3 \longrightarrow 2\ FeCl_3 + 3\ H_2O$

4. reaction with carbonates

acid + carbonate $\longrightarrow$ salt + water + CO_2

$2\ HCl + Na_2CO_3 \longrightarrow 2\ NaCl + H_2O + CO_2$

$H_2SO_4 + MgCO_3 \longrightarrow MgSO_4 + H_2O + CO_2$

$HCl + NaHCO_3 \longrightarrow NaCl + H_2O + CO_2$

15.3 Reactions of bases

1. reaction with acids

2. amphoteric hydroxides

   hydroxide of certain metals – Zn, Al, Cr are **amphoteric**, they are capable of reacting with either an acid or a base

   $Zn(OH)_2 + 2\ HCl \longrightarrow ZnCl_2 + 2\ H_2O$

   $Zn(OH)_2 + 2\ NaOH \longrightarrow Na_2Zn(OH)_4$

3. reaction of NaOH and KOH with certain metals

   base + metal + water $\longrightarrow$ salt + hydrogen

   $2\ NaOH + Zn + H_2O \longrightarrow Na_2Zn(OH)_4 + H_2$

   $2\ KOH + 2\ Al + 6\ H_2O \longrightarrow 2\ KAl(OH)_4 + 3\ H_2$

15.4 Salts

most of the rocks and minerals of Earth's mantle are salts of one kind or another

huge quantities of dissolved salts exist in the ocean

salts can be considered compounds derived from acids and bases

base　　　　　　　　acid

NaOH　　　　　　　　HCl

NaCl

salt

salts are usually crystalline and have high melting point and boiling point

15.5 Electrolytes and nonelectrolytes

solutions of certain substances are conductors of electricity

(a) pure water (b) sugar water (c) salt water

electrolytes – substances whose aqueous solutions are conductors of electricity

nonelectrolytes – substances whose aqueous solutions are conductors

acids, bases and other ionic compounds (salts) are electrolytes

one major difference between electrolytes and nonelectrolytes is that electrolytes are capable of producing ions in solution

Table 15.2 Representative Electrolytes and Nonelectrolytes

Electrolytes		Nonelectrolytes	
H_2SO_4	$HC_2H_3O_2$	$C_{12}H_{22}O_{11}$ (sugar)	CH_3OH (methyl alcohol)
HCl	NH_3	C_2H_5OH (ethyl alcohol)	$CO(NH_2)_2$ (urea)
HNO_3	K_2SO_4	$C_2H_4(OH)_2$ (ethylene glycol)	O_2
$NaOH$	$NaNO_3$	$C_3H_5(OH)_3$ (glycerol)	H_2O

15.6 Dissociations and ionization of electrolytes

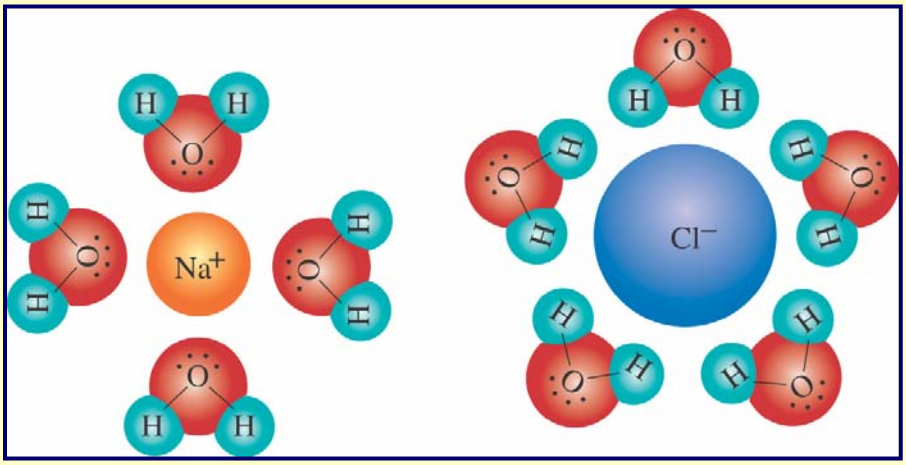
Arrhenius found that a solution conducts electricity because the solute dissociates immediately upon dissolving into electrically charged particles (ions)

dissociation – the process by which the ions of a salt separate as the salt dissolves

ex. NaCl dissolves in water

$$NaCl(s) + (x+y)\ H_2O \longrightarrow Na^+(H_2O)_x + Cl^-(H_2O)_y$$

hydrated sodium and chloride ions



simplify the dissociation equation

$$NaCl(s) \longrightarrow Na^+(aq) + Cl^-(aq)$$

ionization – the formation of ions

ex. glacial acetic acid (100% $HC_2H_3O_2$) is a liquid and a nonelectrolyte, but a water solution of acetic acid conducts electricity

$$HC_2H_3O_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_3O_2^-$$

$$\text{or}\quad HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-$$

ex. $HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

many H_3O^+ and Cl^- ions exist in the solution

dissolving HCl in a nonpolar solvent (hexane), the solution fails to conduct electricity

15.7 Strong and weak electrolytes

strong electrolytes are essentially 100% ionized in solution, **weak electrolytes** are much less ionized

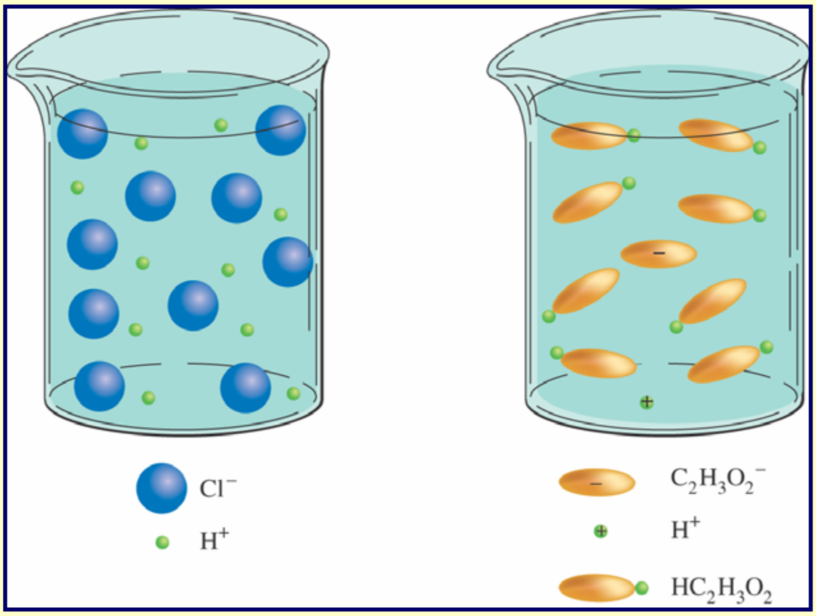
most salts are strong electrolytes

acids and bases that are strong electrolytes are called strong acids and strong bases

acids and bases that are weak electrolytes are called weak acids and weak bases

for equivalent concentrations, solutions of strong electrolytes contain many more ions than do solutions of weak electrolytes

ex. 1 M HCl and 1 M $HC_2H_3O_2$



HCl almost 100% ionized — strong acid

acetic acid is ~1% ionized — weak acid

strong base NaOH and weak base NH_3 can be distinguished in a similar fashion a double arrow ($\rightleftharpoons$) is used in the ionization equation of soluble weak electrolyte to indicate that the solution contains a considerable amount of the un-ionized compound in equilibrium with its ions in the solution

a single arrow ($\longrightarrow$) is used to indicate that the electrolyte is essentially all in the ionic form in the solution

ex. nitric acid a strong acid

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

nitrous acid a weak acid

$$HNO_2(aq) \rightleftharpoons H^+(aq) + NO_2^-(aq)$$

strong and weak electrolytes

Table 15.3 Strong and Weak Electrolytes

Strong electrolytes		Weak electrolytes	
Most soluble salts	$HClO_4$	$HC_2H_3O_2$	$H_2C_2O_4$
H_2SO_4	$NaOH$	H_2CO_3	H_3BO_3
HNO_3	KOH	HNO_2	$HClO$
HCl	$Ca(OH)_2$	H_2SO_3	NH_3
HBr	$Ba(OH)_2$	H_2S	HF

electrolytes yield two or more ions per formula unit upon dissociation

ex. $NaCl \longrightarrow Na^+(aq) + Cl^-(aq)$ 2 ions

$Na_2SO_4 \longrightarrow 2\ Na^+(aq) + SO_4^{2-}(aq)$ 3 ions

$Fe_2(SO_4)_3 \longrightarrow 2\ Fe^{3+}(aq) + 3\ SO_4^{2-}(aq)$

5 ions

ex. 15.2 what is the molarity of each ion in a solution of (a) 2.0 *M* NaCl, (b) 0.4 *M* K_2SO_4

(a) 2.0 *M* Na^+, 2.0 *M* Cl^-

(b) 0.8 *M* K^+, 0.4 *M* SO_4^{2-}

colligative properties of electrolytes

1 mol sucrose is dissolved in 1000 g water, the solution freezes at -1.86°C

1 mol NaCl is dissolved in 1000 g water, the freezing point of the solution is about -3.72°C (-1.86°C × 2)

because 1 mol NaCl in solution produces 2 mol of particles

the colligative properties are affected by substance that yield ions in aqueous solution

15.8 Ionization of water

pure water is a very weak electrolyte

ionization of water

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

acid base acid base

$$H_2O \rightleftharpoons H^+ + OH^-$$

at 25^{o}C, the concentration of H^+ and OH^- is 1.0×10^{-7} *M*

$$[H^+] = 1.0 \times 10^{-7}\ M$$

$$[OH^-] = 1.0 \times 10^{-7}\ M$$

15.9 Introduction to pH

the acidity of an aqueous solution depends on the concentration of hydrogen ions

the pH scale of acidity – negative logarithm of the H^+ concentration in moles per liter

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

the pH of pure water at 25°C is 7

pH < 7.00 is an acidic solution

pH = 7.00 is a neutral solution

pH > 7.00 is a basic solution

the smaller the pH value, the more acidic the solution

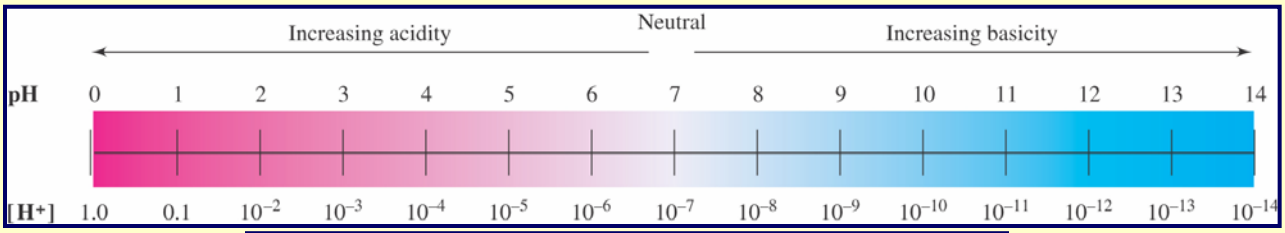


Table 15.4 pH Scale for Expressing Acidity

$[H^+]$ (mol/L)	pH	
1×10^{-14}	14	↑
1×10^{-13}	13	
1×10^{-12}	12	Increasing basicity
1×10^{-11}	11	
1×10^{-10}	10	
1×10^{-9}	9	
1×10^{-8}	8	
1×10^{-7}	7	Neutral
1×10^{-6}	6	
1×10^{-5}	5	
1×10^{-4}	4	
1×10^{-3}	3	Increasing acidity
1×10^{-2}	2	
1×10^{-1}	1	
1×10^{0}	0	↓

pH of some common solutions

Table 15.5 The pH of Common Solutions

Solution	pH
Gastric juice	1.0
0.1 *M* HCl	1.0
Lemon juice	2.3
Vinegar	2.8
0.1 *M* $HC_2H_3O_2$	2.9
Orange juice	3.7
Tomato juice	4.1
Coffee, black	5.0
Urine	6.0
Milk	6.6
Pure water (25°C)	7.0
Blood	7.4
Household ammonia	11.0
1 *M* NaOH	14.0

ex. 15.3 what is the pH of a solution with an $[H^+]$ of (a) 1.0×10^{-11} (b) 6.0×10^{-4} (c) 5.47×10^{-8}

(a) $pH = -\log(1.0 \times 10^{-11}) = 11.00$

(b) $pH = -\log(6.0 \times 10^{-4}) = 3.22$

(c) $pH = -\log(5.47 \times 10^{-8}) = 7.262$

measurement of pH

pH test paper – containing indicators

electronic pH meter

15.10 Neutralization

neutralization – the reaction of an acid and a base to form a salt

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$(H^+ + Cl^-) + (Na^+ + OH^-) \longrightarrow Na^+ + Cl^- + H_2O$$

Na^+ and Cl^- ions did not react, these ions are called spectator ions

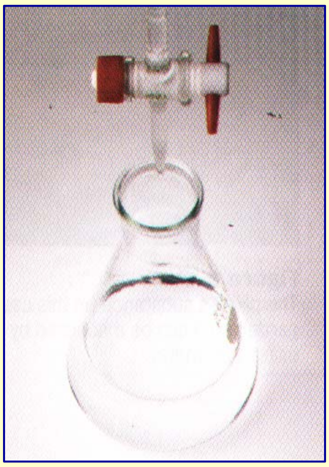
the net ionic equation:

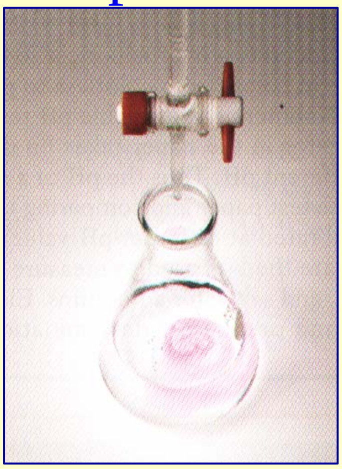
$$H^+ + OH^- \longrightarrow H_2O$$

the amount of acid, base, or other species in a sample can be determined by **titration**

the titration of an acid with a base

indicator end point of the titration





ex. 15.4 42 mL of 0.15 *M* NaOH solution is required to neutralize 50 mL of HCl solution what is the molarity of acid solution?

$0.042\ L \times 0.15\ M = 0.063$ mol NaOH

0.063 mol / 0.05 L $= 0.126\ M$ HCl solution ex. 15.5 42 mL of 0.15 *M* NaOH solution is required to neutralize 50 mL of H_2SO_4 solution

what is the molarity of acid solution?

0.042 L × 0.15 *M* = 0.063 mol NaOH

0.063 mol / 2 = 0.0315 mol H_2SO_4

0.0315 mol / 0.05 L

= 0.063 *M* H_2SO_4 solution

ex. 15.6 25.00-mL sample of H_2SO_4 solution required 14.26 mL 0.224 M NaOH for neutralization

what is the molarity of sulfuric acid?

0.01426 L × 0.224 *M* = 0.0032 mol NaOH

0.032 mol / 2 = 0.016 mol H_2SO_4

0.016 mol / 0.025 L

= 0.064 *M* H_2SO_4 solution

15.11 Writing net ionic equations

the reaction of hydrochloric acid and sodium hydroxide:

1. un-ionized equation

   $HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$

2. total ionic equation

   $(H^+ + Cl^-) + (Na^+ + OH^-) \longrightarrow Na^+ + Cl^- + H_2O$

3. net ionic equation

   $H^+ + OH^- \longrightarrow H_2O$

the rules for writing ionic equations:

1. strong electrolytes in solution are written in their ionic form
2. weak electrolytes are written in their molecular form
3. nonelectrolytes are written in molecular form
4. insoluble substances, precipitates, and gases are written in their molecular form
5. the net ionic equation should include only substances that have undergone a chemical change (spectator ions are omitted)
6. equations must be balanced, both in atoms and in electrical charge

write the net ionic equation for each of the following examples:

ex. 15.7

$HNO_3(aq) + KOH(aq) \longrightarrow KNO_3(aq) + H_2O(l)$

$H^+ + OH^- \longrightarrow H_2O(l)$

ex. 15.8 $2\ AgNO_3(aq) + BaCl_2(aq) \longrightarrow$

$2\ AgCl(s) + Ba(NO_3)_2(aq)$

$Ag^+ + Cl^- \longrightarrow AgCl(s)$

ex. 15.9 $Na_2CO_3(aq) + H_2SO_4(aq) \longrightarrow$

$Na_2(SO_4)_2(aq) + H_2O(l) + CO_2(g)$

$CO_3^{2-} + 2H^+ \longrightarrow H_2O(l) + CO_2(g)$

ex. 15.10 $HC_2H_3O_2(aq) + NaOH(aq) \longrightarrow$

$NaC_2H_3O_2\ (aq) + H_2O(l)$

$HC_2H_3O_2 + OH^- \longrightarrow C_2H_3O_2^- + H_2O(l)$

ex. 15.11

$Mg(s) + 2\ HCl(aq) \longrightarrow MgCl_2\ (aq) + H_2\ (g)$

$Mg(s) + 2\ H^+ \longrightarrow Mg^{2+} + H_2(g)$

ex. 15.12 $H_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow$

$BaSO_4(s) + 2\ H_2O(l)$

$2\ H^+ + SO_4^{2-} + Ba^{2+} + 2\ OH^- \longrightarrow$

$BaSO_4(s) + 2\ H_2O(l)$

15.12 Acid rain

acid rain – any atmospheric precipitation that is more acidic than usual

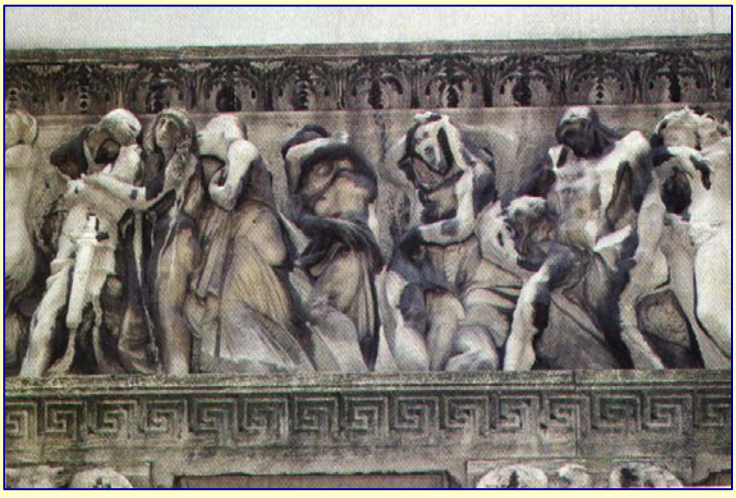
the increase in acidity might be from natural or industrial sources

unpolluted rain has a pH of 5.6 and is slightly acidic which results from the dissolution of CO_2 in water producing carbonic acid

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$
$$\rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$$

general process for the acid rain formation involves the following steps:

1. emission of nitrogen and sulfur oxides into the air
2. transportation of these oxides throughout the atmosphere
3. chemical reactions between the oxides and water forming sulfuric acid and nitric acid
4. rain or snow carries the acids to the ground



15.13 Colloids: an introduction

sugar + water $\longrightarrow$ clear homogeneous solution

very fine sand + water $\xrightarrow{\textit{shaking}}$ suspension

starch + water $\xrightarrow{\textit{heating, stirring}}$ cloudy, opalescent dispersion

colloid – a dispersion in which the dispersed particles are larger than the solute ions or molecules of a true solution and smaller than the particles of a mechanical suspension

the size of colloidal particles: 1 nm ~ 1000 nm

eight types of colloids

Table 15.6 Types of Colloidal Dispersions

Type	Name	Examples
Gas in liquid	foam	whipped cream, soapsuds
Gas in solid	solid foam	Styrofoam, foam rubber, pumice
Liquid in gas	liquid aerosol	fog, clouds
Liquid in liquid	emulsion	milk, vinegar in oil salad dressing, mayonnaise
Liquid in solid	solid emulsion	cheese, opals, jellies
Solid in gas	solid aerosol	smoke, dust in air
Solid in liquid	sol	india ink, gold sol
Solid in solid	solid sol	tire rubber, certain gems (e.g., rubies)

the fundamental difference between a colloidal dispersion and a true solution is the size

the volume of a colloidal particle can be up to 10^9 times greater than that of a solution particle

15.14 Properties of colloids

1827 Brown observed that the pollen grains appeared to have a trembling, erratic motion

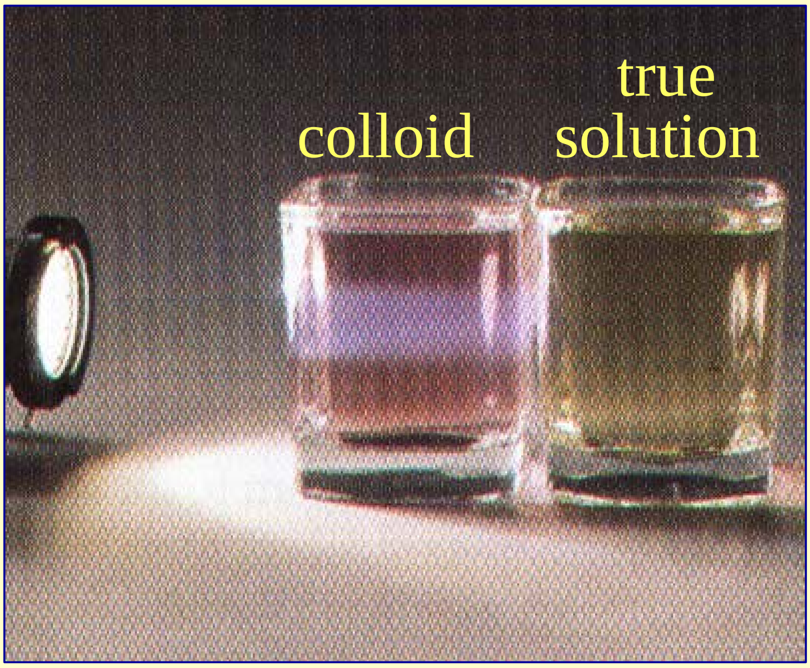
this random motion of colloidal particles is called **Brownian movement**

an intense beam of light is passed through an ordinary solution and the beam passing through the solution is hardly visible

however, a beam of light is clearly visible and sharply outlined when it is passed through a colloidal dispersion – **Tyndall effect**

because the colloidal particles are large enough to scatter the rays of visible light

the colloidal particles have **relatively huge surface areas**



15.15 Applications of colloidal properties

1. activated charcoal has an enormous surface area ~ 10^8 cm^2/g
   - gas mask – selectively adsorbing the polar molecules of some poisonous gases
   - in sugar refineries, to adsorb colored impurities from raw sugar solution
2. Frederick Cottrell   the Cottrell process

   the particulate matter in dust and smoke is electrically charged

   air to be cleaned of dust or smoke is passed between electrode plates charged with a high voltage
3. Thomas Graham

   parchment membrane allows the passage of true solutions but prevents the passage of colloidal dispersions

   dialysis – use of this membrane can remove dissolved solute from colloidal dispersions

   the membrane is called dialyzing membrane

   life-saving application is development of artificial kidneys