# Solutions and acid-base chemistry slide deck

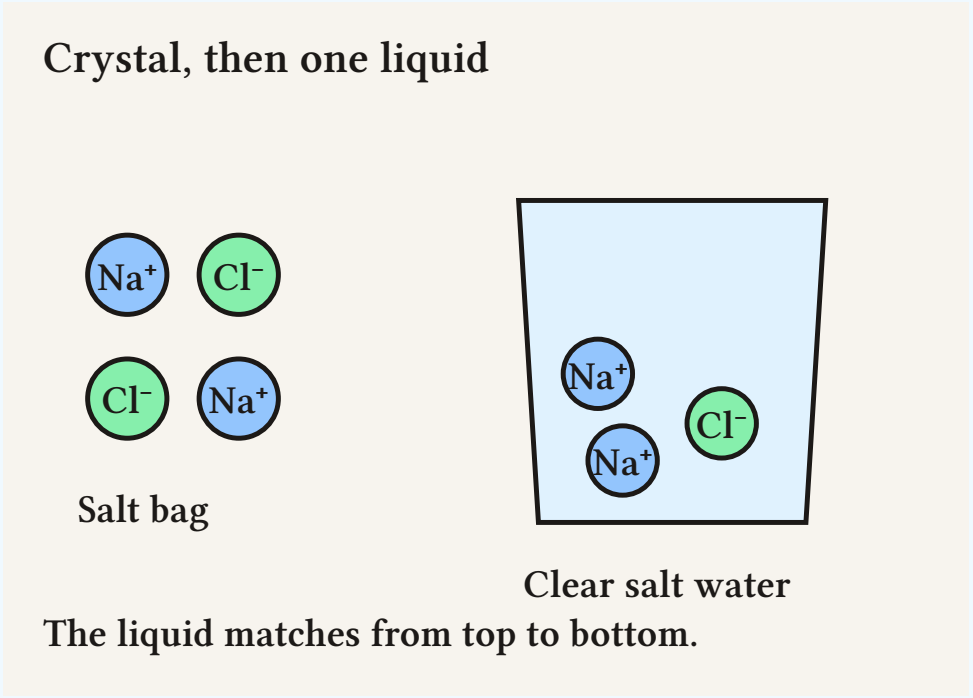
Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Homogeneous mixtures and dissolving

# Solutions and mixtures

- A sealed bag of road salt holds the pure substance sodium chloride, and every crystal has the same ion ratio.
- Salt stirred into water until the solid disappears leaves one clear liquid with matching composition from top to bottom.



## Uniform mixing comes before many changes

- Pure substances are elements or compounds, and mixtures are either uniform solutions or samples with visible parts.
- Dissolved ions or molecules can collide, which is why dissolving in water often comes before a chemical change.

# Key terms

**pure substance**

Matter made of one element or one compound, with a fixed composition. (NaCl)

**solution**

A homogeneous mixture with one visible phase and the same composition in every portion. (salt water)

**solute**

The substance whose particles spread through the solvent when a solution forms. (NaCl)

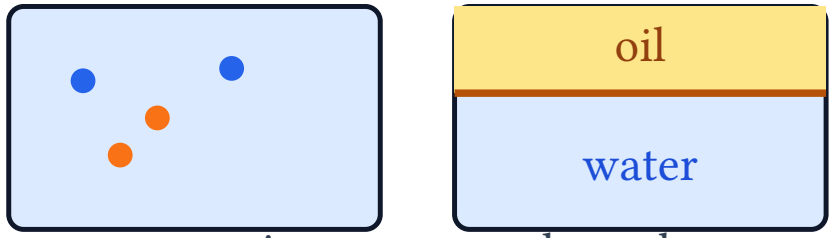
**solvent**

The substance that does the dissolving and is usually present in the greater amount. (water)

# One phase means one particle ratio

- Solute particles spread among solvent particles until every small region has the same ratio.
- Oil over water, or sand under clearer water, keeps a boundary and more than one phase.

**One phase vs boundaries**




Dissolving spreads solute until uniform

## Why the cold pack feels cold

- Pulling solute particles apart and pulling solvent particles apart both absorb energy.
- Attractions that form between solute and solvent release energy, and the larger total sets the temperature change.

## Completing the warm-pack tally

- A calcium chloride warm pack warms the skin when the new attractions release more energy than separation absorbs.
- The same comparison of two totals decides any dissolving sample once the energies are given.

## Phase and energy sign

- Classify filtered copper sulfate solution and orange juice with pulp by the number of phases.
- Use 55 kJ absorbed and 30 kJ released to state the net energy and the temperature direction.

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Electrolytes and solubility

## One lamp on, one lamp dim

- Aqueous sodium chloride closes a conductivity circuit and the lamp glows.
- Aqueous sucrose, table sugar in water, leaves that same lamp dim.

# Electrolytes and saturation

- An electrolyte produces mobile ions and the solution conducts. A nonelectrolyte such as sugar stays as whole molecules.
- Solubility is a maximum at a stated temperature, and a saturated solution keeps that maximum by equal rates.

# Key terms

### electrolyte

A substance that produces mobile ions in solution so the solution conducts electricity. (NaCl(aq))

### nonelectrolyte

A substance that dissolves as whole molecules, so the solution conducts poorly. (sucrose(aq))

### solubility

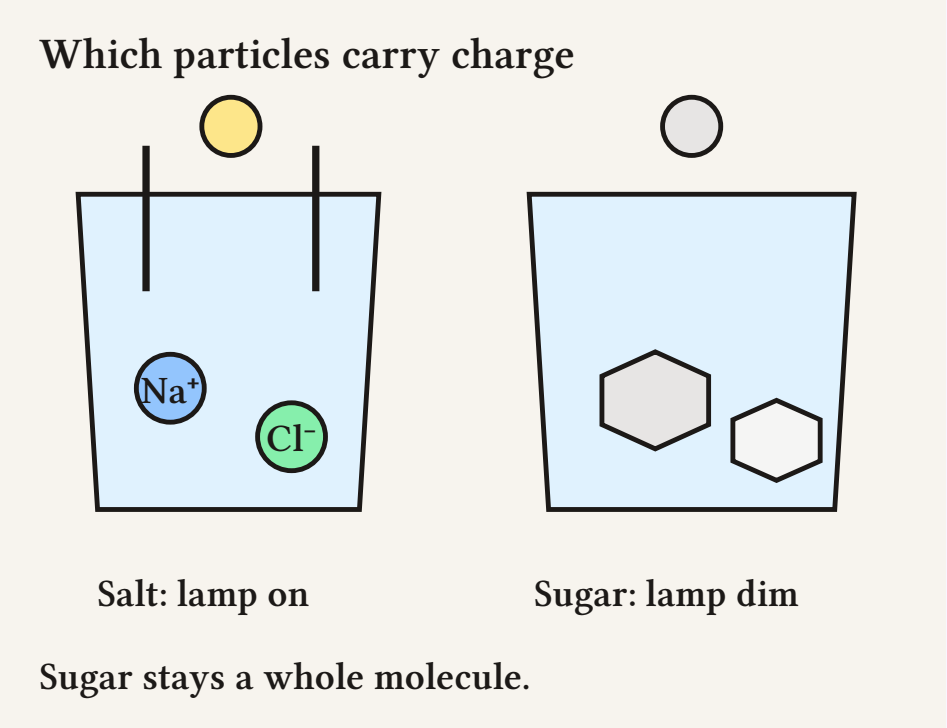
The maximum amount of solute that dissolves in a stated amount of solvent at a stated temperature. (g per 100 g water at 20 °C)

### saturated solution

A solution in which dissolving and crystallization continue at equal rates, so the concentration stays steady. (solid still present)

# Charge that can travel

- Sodium ions and chloride ions move through water and carry charge to the probes.
- Sucrose molecules spread through water and remain uncharged, so the current stays tiny.



## Equal rates, steady dissolved amount

- In a saturated solution, undissolved solid remains in contact with the dissolved solute.
- The dissolving count and the crystallization count match, so the concentration holds steady.

## Factors that affect solubility

- Many solids become more soluble in warmer solvent, and gases become less soluble in warmer solvent.
- Gas solubility rises when the gas pressure rises. Ethanol and water mix in all proportions, and oil and water form two layers.

# Lamp and limit

- Explain the lamp in aqueous calcium chloride and in aqueous glucose.
- State what equal leave and return rates do to concentration, and what warming does to dissolved oxygen.

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Concentration of solutions

## Three tags on salty water

- A clinic bag, a lab bottle, and a river report can all describe salty water with different numbers.
- Each number is a ratio, and the ratio is useful only when its unit is named beside it.

## Concentration ratios

- $c = n/V$. Here n is moles and V is litres.
- Percent by mass and parts per million, ppm, both compare solute mass with solution mass.
- The unit $mol \cdot L^{-1}$ means moles of solute in one litre of solution.

# Key terms

### molar concentration

The amount of solute in moles divided by the volume of solution in litres. The unit $mol \cdot L^{-1}$ means moles of solute in one litre of solution. ($c = n/V$)

### percent by mass

The mass of solute divided by the mass of solution, multiplied by 100. (% (m/m))

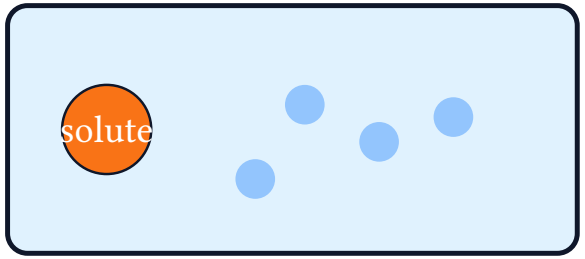
### parts per million

The mass of solute divided by the mass of solution, multiplied by one million. The symbol is ppm. (ppm)

# The denominator is the whole solution

- Percent by mass divides by the mass of solute plus the mass of solvent.
- A ppm value uses the same solution mass, then scales the ratio by one million.

**Denominator = whole solution**




mass solute + mass solvent

ppm = same ratio × $10^6$

## From 2.922 g of salt to mol·L$^{-1}$

- Convert the measured mass to moles with the molar mass, and convert millilitres to litres.
- Divide the moles by the litres to get c in mol·L$^{-1}$.

## From mol·L$^{-1}$ back to grams

- Multiply c by V, with V in litres, to get the amount of solute in moles.
- Multiply that amount by the molar mass to get the mass to measure.

## Concentration units

- Find the percent by mass for 12.0 g of solute dissolved in 108.0 g of water.
- Find c for 1.461 g of NaCl made up to 100.0 mL, and find ppm for 7.5 mg of solute in 1.50 kg of solution.

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Dilution and ion concentration

# A strong bottle and a milder target

- The stock is 2.00 $\mathrm{mol \cdot L^{-1}}$ and the target is 0.200 $\mathrm{mol \cdot L^{-1}}$ in 500.0 mL.
- The solute that ends in the flask is a measured portion of that stock, then water fills the flask to the mark.

## The amount of solute stays the same

- Symbol $c_1$ is the stock concentration and $V_1$ is the stock volume.
- The product of concentration and volume is the amount of solute, and dilution leaves that amount unchanged.
- Symbol $c_2$ is the diluted concentration and $V_2$ is the final volume.

# Key terms

### dilution

Adding solvent so the solution volume rises, the concentration falls, and the amount of solute stays the same. ($c_1 V_1 = c_2 V_2$)

### dissociation

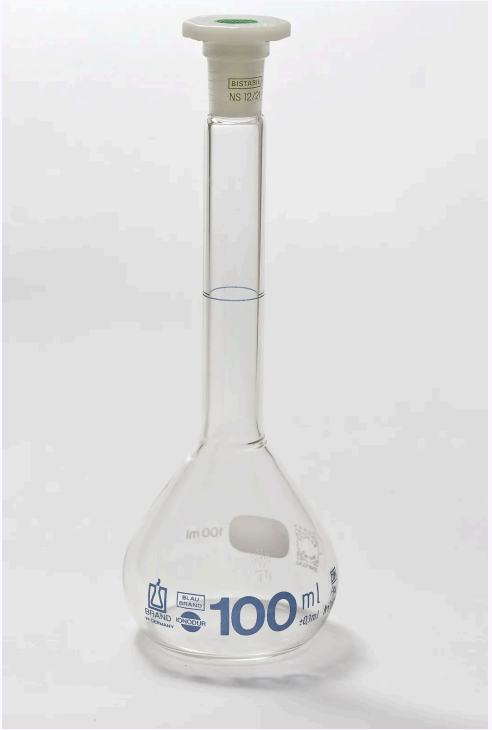
The separation of a dissolved ionic compound into positive ions and negative ions. ($CaCl_2(aq)$)

### volumetric flask

A flask with one calibration mark used to hold a stated final volume of solution. (500.0 mL mark)

# The volumetric flask mark

- Calculate the mass, dissolve the solid in some water already in the volumetric flask, then fill to the mark.
- Read the label and wear goggles before the solid is transferred.



# Diluting 50.0 mL of stock

- Solve $c_1 V_1 = c_2 V_2$ for the stock volume that supplies the solute.
- Add water until the final volume is the flask mark. The volume difference only estimates the water.

## Two chloride ions for each formula

- Calcium chloride dissociates as $CaCl_2(aq)$ to $Ca^{2+}(aq)$ plus 2 $Cl^-(aq)$.
- The coefficient of each ion multiplies the compound concentration.

## Volume and ions

- Find the stock volume of 3.00 $\text{mol}\cdot\text{L}^{-1}$ solution that prepares 250.0 mL of 0.150 $\text{mol}\cdot\text{L}^{-1}$ solution.
- Find $[\text{Na}^+]$ and $[\text{SO}_4^{2-}]$ in 0.200 $\text{mol}\cdot\text{L}^{-1}$ $\text{Na}_2\text{SO}_4$.

# Image credits

Lucasbosch, Brand volumetric flask 100ml, CC BY-SA 3.0

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Solutions in society and the laboratory

## Solutions in daily life

- Sports drinks, intravenous saline, and river samples are all solutions people measure on purpose.
- The number on each container is a concentration chosen for that use.

## Three communities, three unit habits

- Laboratories use mol·L$^{-1}$, households use percent, and environmental studies often use ppm or mg/L.
- Responsible Care members commit to safe handling and to reports the public can read.

# Key terms

### biomagnification

The rise in concentration of a stored substance along a food chain, so predators hold more than the water did. (methylmercury)

### Responsible Care

The Chemistry Industry Association of Canada program, begun under the Canadian Chemical Producers' Association, in which member companies commit to safe handling and public reporting. (public reports)

### stewardship

A commitment to meet a human need while keeping the environment able to recover, shown here by a smaller release and a downstream check. (effluent plan)

### effluent

Wastewater released from a process into a waterway. (plant outflow)

# Key terms

**WHMIS**

The Workplace Hazardous Materials Information System, which uses labels and pictograms to communicate hazards before a product is handled. (pictogram)

# Stored substances climb the food chain

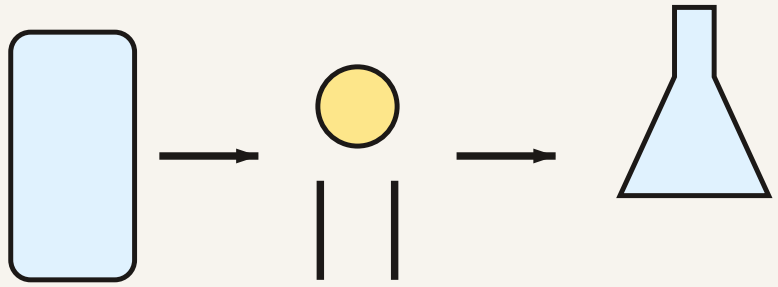
- Biomagnification turns a tiny concentration in water into a much larger concentration in predators.
- A risk-benefit judgment depends on the concentration and on who is exposed.



# A procedure that starts with the label

- Read the WHMIS pictograms and the consumer label, then test conductivity and measure a solid solute.
- Use a balance and a volumetric flask, and compare the calculated concentration with another group.

Label, then the measurement



Bottle label  Test probes  Volume flask

Compare your result with a partner.

## Reducing a release

- Two groups who aimed at the same target compare their calculated concentrations on one graph.
- A stewardship plan names a smaller effluent release and a downstream concentration check.

## Unit and commitment

- Match a lab stock, a household cleaner, and a river metal to mol·L$^{-1}$, percent, and ppm or mg/L.
- State the smaller release and the downstream check in one stewardship plan.

# Image credits

Sumeet Moghe, Osprey in flight with a fish kill, CC BY-SA 4.0

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Naming and testing acids and bases

## Formulas and product labels

- HCl(aq) is hydrochloric acid, $H_2SO_4$(aq) is sulfuric acid, $HNO_3$(aq) is nitric acid, and $CH_3COOH$(aq) is ethanoic acid.
- NaOH(aq) is sodium hydroxide, the base that sits in the same recall set as those four acids.

## Names first, then the empirical tests

- Each aqueous formula in the recall set has one IUPAC name, and the (aq) symbol is part of that match.
- Indicator colour, a pH reading, and conductivity are the empirical tests used to sort acidic, neutral, and basic solutions.

# Key terms

### aqueous acid

An acid whose IUPAC name is used when the formula is marked as dissolved in water. (HCl(aq))

### hydronium ion

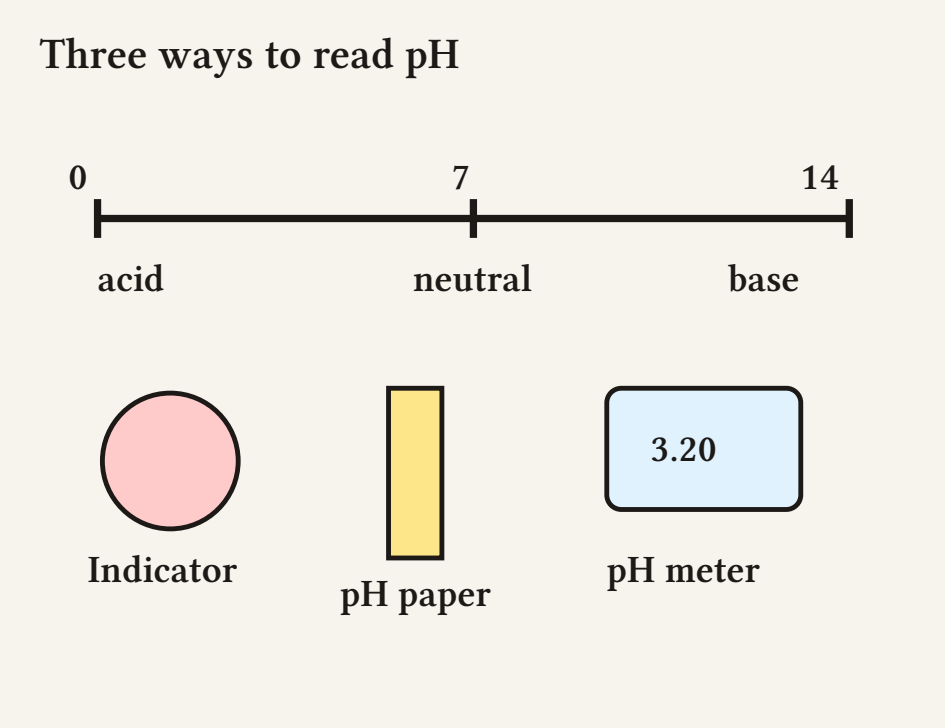
The ion $H_3O^+(aq)$. Square brackets in $[H_3O^+]$ mean its concentration in $mol \cdot L^{-1}$. ($[H_3O^+]$)

### pH

The number from $pH = -\log[H_3O^+]$. At 25 °C, values below 7 are acidic, 7 is neutral, and values above 7 are basic. ($pH = -\log[H_3O^+]$)

# Indicators and pH meters

- At 25 °C, acidic solutions have pH below 7, neutral solutions have pH 7, and basic solutions have pH above 7.
- An indicator uses a colour match, pH paper uses a paper scale, and a pH meter converts a voltage into pH.

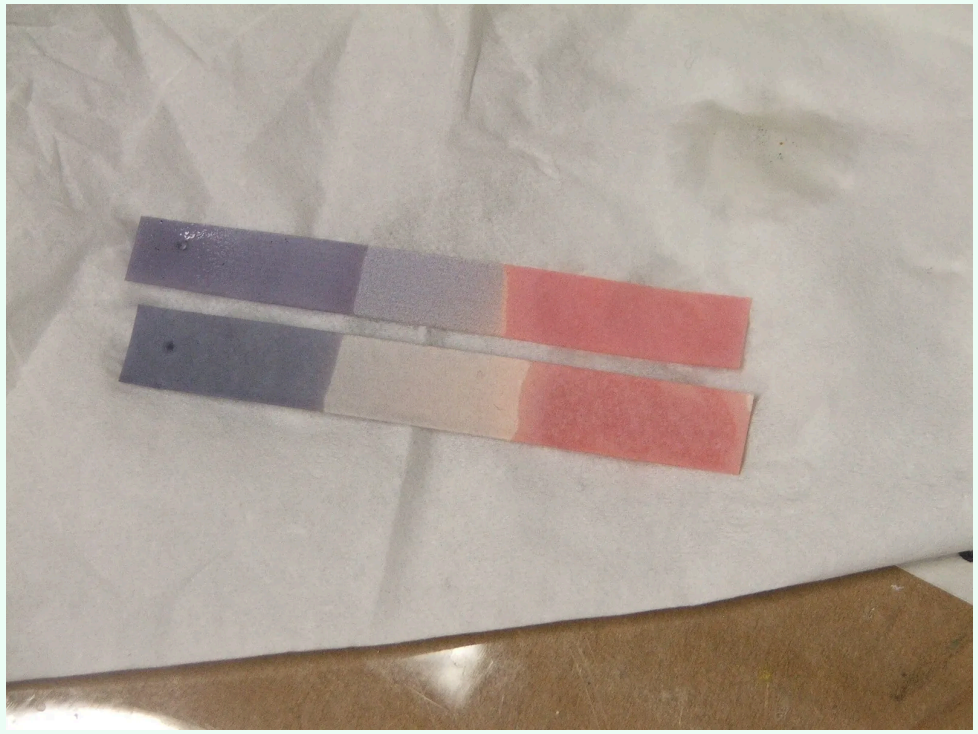


## Three observations, one category

- Blue litmus turns red, the display reads pH 3.1, and the conductivity bulb lights.
- The sample is acidic at 25 °C because 3.1 sits below 7.

# A cleaner above the neutral mark

- Red litmus turns blue, pH paper matches 10.5, and the solution conducts.
- The number 10.5 is above 7, so at 25 °C the cleaner is basic.



# Retrieval of names and a neutral trap

- Give the IUPAC names for $HNO_3(aq)$ and $CH_3COOH(aq)$.
- Classify a conducting sample at pH 7.0 and 25 °C.

# Image credits

Chemicalinterest, Litmus paper, public domain

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# pH and pOH

# Significant digits in meter readings

- pH 3.20 comes from a hydronium concentration of $6.3 \times 10^{-4}$ $mol \cdot L^{-1}$.
- The SI unit on that concentration is $mol \cdot L^{-1}$, moles of solute per litre of solution.



## Powers of ten, then the water sum

- A hydronium concentration of $1.0 \times 10^{-3}$ mol·L$^{-1}$ gives pH 3.00.
- A hydroxide concentration of $1.0 \times 10^{-3}$ mol·L$^{-1}$ gives pOH 3.00 and pH 11.00 at 25 °C, because pH + pOH = 14.00.

# Key terms

### hydronium concentration

The amount of $H_3O+$ in one litre of solution, written $[H_3O+]$ and measured in $mol \cdot L^{-1}$. ($[H_3O+]$)

### pOH

The number $-\log[OH^-]$, where $[OH^-]$ is the hydroxide ion concentration in $mol \cdot L^{-1}$. ($pOH = -\log[OH^-]$)

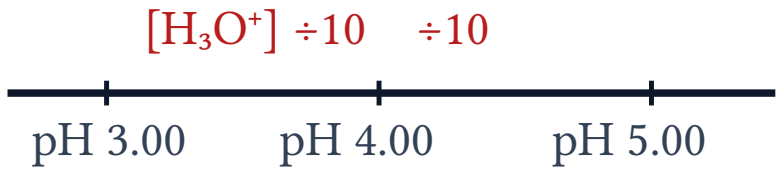
### significant digits

The digits in a concentration that are fixed by how many decimal places the pH value shows. (pH 3.20)

# Decimal places and a tenfold jump

- The number of decimal places in a pH value equals the significant digits in the concentration.
- A decrease of 1.00 in pH multiplies [$H_3O+$] by 10, and a decrease of 1.00 in pOH multiplies [$OH^-$] by 10.

**pH decimals and ×10 jumps**




2 decimals in pH ⟶ 2 sig figs in [$H_3O^+$]

Each +1 pH: [$H_3O^+$] is 10× smaller

## From pH 3.20 back to mol·L$^{-1}$

- pH 3.20 has two decimal places, so the concentration has two significant digits.
- The matching hydronium concentration is $6.3 \times 10^{-4}$ mol·L$^{-1}$.

## A one-unit drop on the hydroxide scale

- At 25 °C, pOH 3.00 belongs with $[OH^-] = 1.0 \times 10^{-3}$ mol·L$^{-1}$ and with pH 11.00.
- If that pOH decreases by 1.00, the hydroxide concentration is multiplied by 10.

# Powers of ten

- Find the pH when $[H_3O+] = 1.0 \times 10^{-3}\ \text{mol·L}^{-1}$.
- pH 3.20 allows two significant digits in $[H_3O+]$, reported as $6.3 \times 10^{-4}\ \text{mol·L}^{-1}$.

# Image credits

OER CampLev, PH-Meter METTLER TOLEDO FiveEasy, CC BY-SA 4.0

Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Modified Arrhenius theory and neutralization

# Hydrogen chloride meets water

- $HCl(g) + H_2O(l) \longrightarrow H_3O{+}(aq) + Cl^{-}(aq)$ produces the hydronium ion in water.
- A modified Arrhenius acid is defined by that aqueous hydronium, so the definition is limited to water.

# Acids and bases in water

- You will write the hydronium equation for hydrogen chloride and state the aqueous limit of the acid definition.
- You will write hydroxide equations for sodium hydroxide and ammonia, then tally neutralization to 2 $H_2O(l)$.

# Key terms

### modified Arrhenius acid

A substance that produces $H_3O+(aq)$, the hydronium ion, in aqueous solution. ($HCl(g) + H_2O(l)$)

### modified Arrhenius base

A substance that produces $OH^-(aq)$, the hydroxide ion, in aqueous solution. ($NH_3(aq)$)

### neutralization

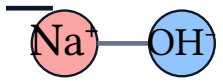
The reaction of hydronium with hydroxide to form water. ($H_3O+(aq) + OH^-(aq) \longrightarrow 2\ H_2O(l)$)

# Sources of hydroxide

- $NaOH(s) \longrightarrow Na^+(aq) + OH^-(aq)$ shows full dissociation of the ionic solid in water.
- $NH_3(aq) + H_2O(l)$ in water makes some $NH_4+(aq)$ and $OH^-(aq)$. The formula $NH_3$ has no OH group, and only part of the ammonia reacts.

**Sources of $OH^-$**

$NaOH(s) \longrightarrow Na^+(aq) + OH^-(aq)$




full dissociation

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




$NH_3$ has no OH group; only part reacts

# Hydronium plus hydroxide makes two waters

- Neutralization is $H_3O^+(aq) + OH^-(aq) \longrightarrow 2\ H_2O(l)$.
- The tally is 4 H, 2 O, and charge zero on both sides.

# Completing the ammonia equation

- Ammonia in water produces $NH_4^+(aq)$ and $OH^-(aq)$.
- The formula $NH_3$ contains no hydroxide group, and the modified definition still counts the aqueous hydroxide.

## Retrieval of three equations

- Write the modified Arrhenius acid equation for HCl(g) with water.
- Write neutralization as hydronium plus hydroxide, with the coefficient on water.

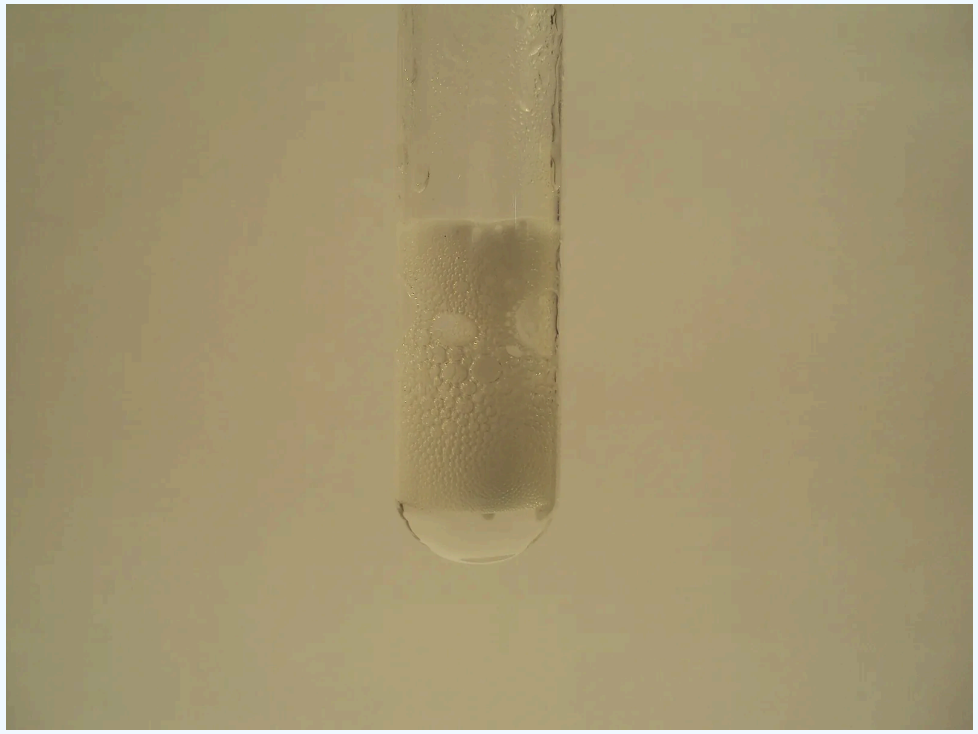
Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Acid strength and polyprotic acids

# Same concentration, different fizz

- At 0.10 mol·L$^{-1}$, hydrochloric acid ionizes completely and ethanoic acid ionizes only partly.
- The hydrochloric acid sample has the lower pH, the faster reaction with carbonate, and the higher conductivity.



## Strength is the fraction ionized

- NaOH dissociates fully, while $NH_3$ ionizes only partly, so the strong base has more hydroxide and higher conductivity at equal concentration.
- After the strong-weak comparison, you will count how many protons HCl, $H_2SO_4$, $H_3PO_4$, NaOH, and carbonate can transfer.

# Key terms

### strong acid

An acid that ionizes completely in water, so the dissolved amount becomes hydronium and the anion. ($HCl(aq)$)

### weak acid

An acid that ionizes only partly in water, so most of the molecules remain intact. ($CH_3COOH(aq)$)

### polyprotic acid

An acid that can donate more than one proton, and does so in steps, with the first step more complete. ($H_2SO_4$)

# Monoprotic and polyprotic acids

- Monoprotic HCl donates one proton, and monoprotic NaOH supplies one $OH^-$.
- Polyprotic $H_2SO_4$ and $H_3PO_4$ can donate more than one proton in steps, and $CO_3^{2-}$ can accept more than one.

**Mono- vs polyprotic**

**Monoprotic** 


$HCl \longrightarrow H^+ + Cl^-$ (one $H^+$)

$NaOH \longrightarrow Na^+ + OH^-$ (base, one $OH^-$)

**Polyprotic** 


$H_2SO_4 \longrightarrow HSO_4^- \longrightarrow SO_4^{2-}$ (2 steps)

$H_3PO_4$: up to 3 $H^+$, one at a time

Polyprotic base: $CO_3^{2-}$ can accept 2 $H^+$

## Sulfuric acid in two steps

- $H_2SO_4$ donates a proton completely to form $HSO_4^-$, then $HSO_4^-$ donates a second proton only partly.
- HCl donates one proton and stops, so hydrochloric acid is mono-protic.

# Monoprotic and polyprotic bases

- NaOH supplies one $OH^-$, so it is a monoprotic base.
- $CO_3^{2-}$ can accept more than one proton, so carbonate is a polyprotic base.

## Retrieval of strength and proton count

- At 0.10 mol·L$^{-1}$, compare HCl and ethanoic acid on pH, carbonate rate, and conductivity.
- Classify $H_3PO_4$ and NaOH as polyprotic or monoprotic.

# Image credits

Dr.T, HCl & magnesium, CC BY-SA 3.0

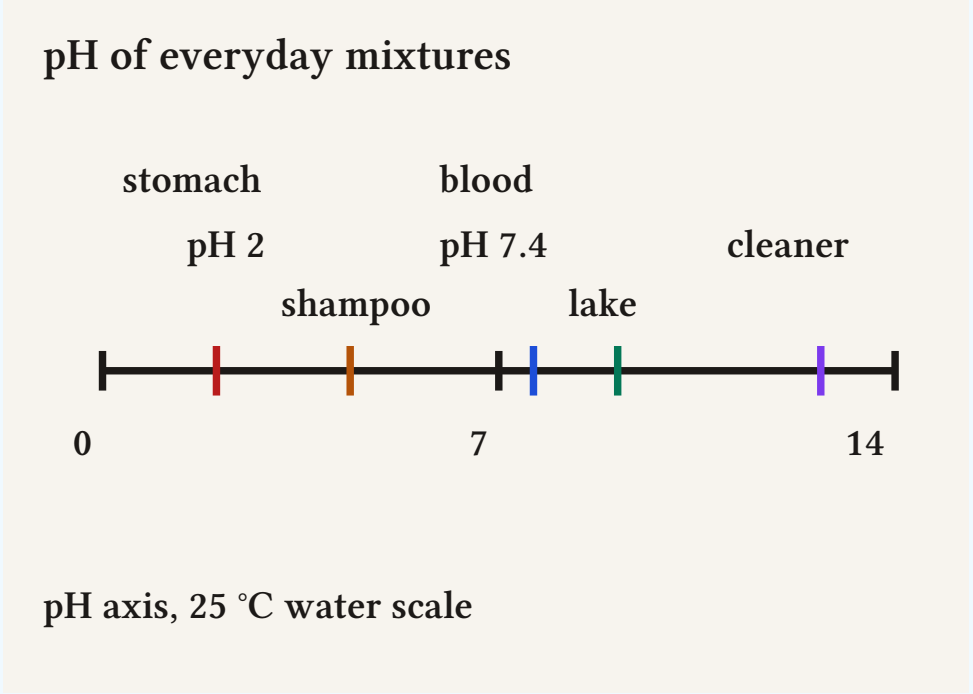
Chemistry 20

## Unit C: Solutions and acid-base chemistry

# Acids and bases in Alberta

# Acids in daily life

- Stomach acid sits near pH 2, blood near 7.4, and many cleaners are basic.
- Pulp and paper, petrochemicals, food preservation, and a car battery all put acid and base chemistry to work.



## Strength and concentration

- Solution strength and concentration both matter for pharmaceuticals, spills, transport of dangerous goods, and toxicity.
- You will design indicator, pH, and conductivity tests, graph hydronium against pH, and read WHMIS labels before any container is opened.

# Key terms

### solution strength

How completely an acid or base forms ions in water, a different fact from how many moles are dissolved per litre. (complete or partial)

### acid deposition

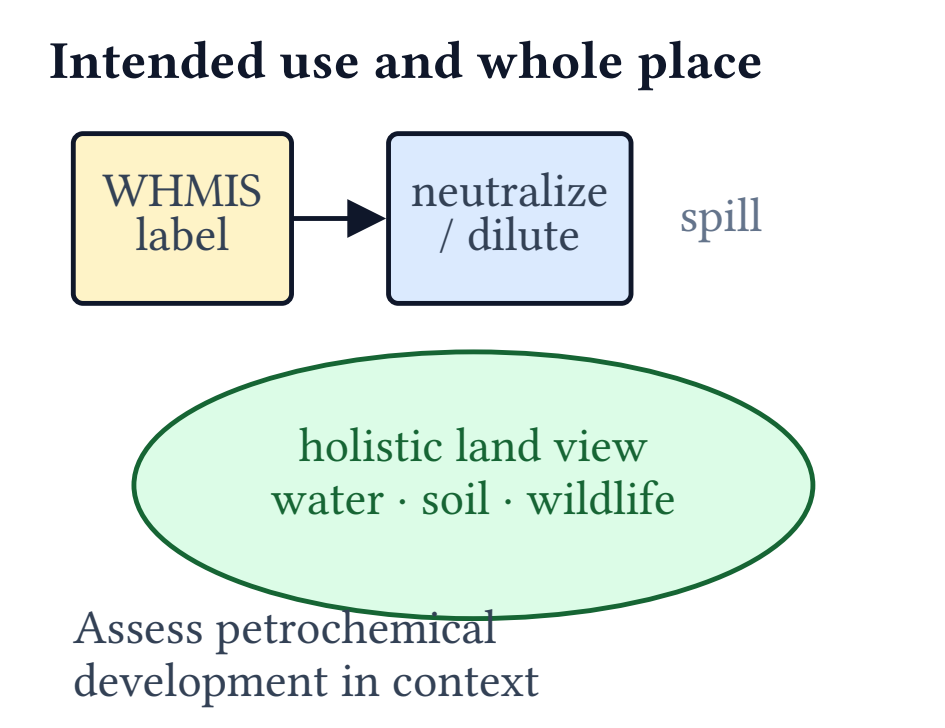
Acid that reaches land and water after gases such as sulfur dioxide and nitrogen oxides form acids in the air. ($SO_2$ and NOx)

### corrosive

The WHMIS and Class 8 dangerous-goods description of many acids and bases that damage tissue and metal. (Class 8)

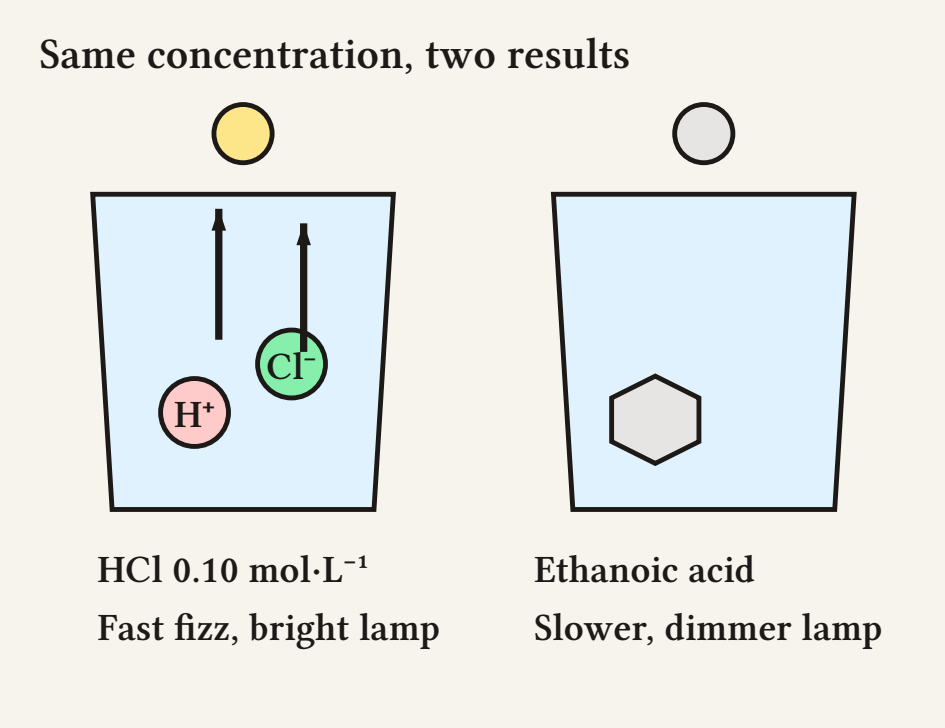
# Intended uses and the whole place

- Spill response uses neutralization and dilution only after the label and the WHMIS information are read.
- Some Indigenous communities in Alberta use holistic land practices when they assess petrochemical development.



# Design the tests and the falling graph

- Indicator colour and pH separate acidic, basic, and neutral samples after the WHMIS label is read.
- At equal concentration, conductivity and the carbonate rate separate a strong acid from a weak acid.



## A corrosive drum and a household pair

- A drum of sulfuric acid is a Class 8 corrosive and needs a WHMIS plan and a dangerous-goods plan.
- Vinegar is acidic ethanoic acid, and a cleaner at pH 12 is basic.

## Industry and emissions

- Sulfuric acid links fertilizer, pulp, batteries, and petrochemicals to industrial growth.
- Scrubbers and catalytic converters cut gases that lead to acid deposition, and water treatment, food science, and environmental chemistry are career paths.