Unit 10 · Inorganic Materials

STUDY NOTES

Key terms

Oxidation: adding oxygen or removing hydrogen.
Reduction: removing oxygen or adding hydrogen.

Oxidizing agent: gives oxygen or takes hydrogen.
Reducing agent: takes oxygen or gives hydrogen.

Catalyst: changes the rate of a reaction without itself being permanently changed; written over the arrow.

Rate: amount of product formed each second or minute.

Activation energy: energy a collision needs for particles to react.

Nascent oxygen [O]: very reactive form given up by HOCl.

Deliquescent: takes water from the air, turns damp.

Saponification: fat + NaOH → soap + glycerol.

Alloy: homogeneous mixture of a metal with other metals or a non-metal, melted together.

Amalgam: alloy of mercury.

Formulas

$\text{gold} = \frac{\text{carats}}{24} \times \text{mass}$	carats: parts of gold in 24 **Use:** 22 carats = 91.7%; 18 carats = 75%
$\text{metal} = \frac{\%}{100} \times \text{mass of alloy}$	check that the masses add up **Use:** how much of each metal

- 10 °C rise roughly doubles the rate, for many reactions
- $CuO + H_2 \rightarrow Cu + H_2O$: CuO reduced (oxidizing agent), H_2 oxidized (reducing agent)

10.1 Oxygen

- supports burning, doesn't burn; strong **oxidizing agent**
- metals
  - $2Mg + O_2 \rightarrow 2MgO$
  - $3Fe + 2O_2 \rightarrow Fe_3O_4$ (sparks)
  - $4Al + 3O_2 \rightarrow 2Al_2O_3$ (protective film)
- moist air + iron: rust, $Fe_2O_3 \cdot xH_2O$
- non-metals
  - $C + O_2 \rightarrow CO_2$
  - $S + O_2 \rightarrow SO_2$
  - $4P + 5O_2 \rightarrow 2P_2O_5$
  - $2H_2 + O_2 \rightarrow 2H_2O$
  - $N_2 + O_2 \rightarrow 2NO$ (very high temperature)
- compounds
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - $2CO + O_2 \rightarrow 2CO_2$
  - $2H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$
  - $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$
- ozone: $3O_2 \rightarrow 2O_3$ (spark, UV)

Oxide	Behaves	Examples
basic (metals)	+ acid → salt + water; alkali: red litmus blue	Na_2O, MgO, CaO, CuO
acidic (most non-metals)	+ base → salt + water; acid: blue litmus red	CO_2, SO_2, SO_3, P_2O_5
amphoteric	reacts with both	ZnO, Al_2O_3
neutral	neither	CO, NO, N_2O, H_2O

- $ZnO + 2HCl \rightarrow ZnCl_2 + H_2O$; $ZnO + 2NaOH \rightarrow Na_2ZnO_2 + H_2O$

Rate of reaction

- $2H_2O_2 \rightarrow 2H_2O + O_2$ (MnO_2 over the arrow); glowing splint bursts into flame
- MnO_2 comes out the same mass, still works: same oxygen in the end, without it months
- particles must **collide**, with the **activation energy**; catalyst: easier path, lower activation energy
- **heat**: faster, more often, harder
- **concentration**: more particles per mL
- **surface area**: powder > lump of same mass
- marble in excess acid: same CO_2 in the end, only **how fast** changes
- change **one thing at a time**

Sulphur

- S_8 rings, written S
- yellow, brittle
- heated, it combines with most metals
- burns with a blue flame: $S + O_2 \rightarrow SO_2$
- $Fe + S \rightarrow FeS$
- $Zn + S \rightarrow ZnS$
- $2Cu + S \rightarrow Cu_2S$
- $Hg + S \rightarrow HgS$ (cold: sprinkled over spilled mercury)
- $H_2 + S \rightarrow H_2S$ (rotten eggs); $C + 2S \rightarrow CS_2$ (red hot)
- hot conc. acids: $S + 2H_2SO_4 \rightarrow 3SO_2 + 2H_2O$; $S + 6HNO_3 \rightarrow H_2SO_4 + 6NO_2 + 2H_2O$; dilute: no effect
- uses
  - sulphuric acid
  - hardening rubber
  - matches
  - gunpowder
  - fungicides

Chlorine

- greenish-yellow
- choking
- poisonous
- about 2.5 × as dense as air
- made: $MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$ (heat)
- $H_2 + Cl_2 \rightarrow 2HCl$: slow in dim light, explodes in sunlight
- $2Na + Cl_2 \rightarrow 2NaCl$
- $2Fe + 3Cl_2 \rightarrow 2FeCl_3$
- $Cu + Cl_2 \rightarrow CuCl_2$
- $Cl_2 + H_2O \rightleftharpoons HCl + HOCl$
- $HOCl \rightarrow HCl + [O]$
- [O] oxidizes dyes: **moist only**, also kills bacteria
- cold, dilute: $Cl_2 + 2NaOH \rightarrow NaCl + NaOCl + H_2O$
- hot, conc.: $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$
- bleaching powder: $Ca(OH)_2 + Cl_2 \rightarrow CaOCl_2 + H_2O$ (really mainly $Ca(OCl)_2$)
- displaces: $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$; $Cl_2 + 2KI \rightarrow 2KCl + I_2$ (brown)
- $H_2S + Cl_2 \rightarrow 2HCl + S$
- uses
  - drinking water
  - bleaching paper and cotton
  - PVC
- Scheele 1774
- Davy, element, 1810
- Semmelweis 1847, about 18 in 100 → 2

Water

- neutral
- $2Na + 2H_2O \rightarrow 2NaOH + H_2$
- $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
- steam
  - $Mg + H_2O \rightarrow MgO + H_2$
  - $3Fe + 4H_2O \rightleftharpoons Fe_3O_4 + 4H_2$
  - Cu, Ag, Au: none
- water gas: $C + H_2O \rightarrow CO + H_2$ (1,000 °C)
- $CaO + H_2O \rightarrow Ca(OH)_2$ + heat
- $Na_2O + H_2O \rightarrow 2NaOH$
- $CO_2 + H_2O \rightleftharpoons H_2CO_3$
- $SO_3 + H_2O \rightarrow H_2SO_4$
- test: $CuSO_4$ (white) + $5H_2O \rightarrow CuSO_4 \cdot 5H_2O$ (blue)
- $2H_2O \rightarrow 2H_2 + O_2$ (electrolysis, 2 : 1)

Hydrochloric acid

- strong: $HCl \rightarrow H^+ + Cl^-$
- conc. about 36%
- stomach pH about 1–3
- dry HCl gas isn't an acid: no ions, dry litmus unchanged
- $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
- $Mg + 2HCl \rightarrow MgCl_2 + H_2$
- $Fe + 2HCl \rightarrow FeCl_2 + H_2$ (**not** $FeCl_3$)
- Cu, Ag, Au: none
- $NaOH + HCl \rightarrow NaCl + H_2O$
- $CuO + 2HCl \rightarrow CuCl_2 + H_2O$
- $CaO + 2HCl \rightarrow CaCl_2 + H_2O$
- $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$
- $Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$
- $NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$
- test: $AgNO_3 + HCl \rightarrow AgCl$ (white, darkens in sun) + HNO_3
- $NH_3 + HCl \rightarrow NH_4Cl$ (white fumes)
- uses
  - pickling steel
  - cleaning tiles
  - aqua regia (with HNO_3, 3 : 1) dissolves gold

Sodium hydroxide

- caustic soda
- strong alkali
- soapy, burns skin
- red litmus blue, phenolphthalein pink
- from brine
- $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$
- $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$
- $2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$
- left open: damp and crusty

Added to	Precipitate
$CuSO_4$	$Cu(OH)_2$, blue
$FeSO_4$	$Fe(OH)_2$, dirty green
$FeCl_3$	$Fe(OH)_3$, reddish brown

- test: $NH_4Cl + NaOH \rightarrow NaCl + NH_3 + H_2O$ (warm; damp red litmus blue)
- hot solution: $Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2$; $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$: never clean aluminium pots with it
- uses
  - soap
  - detergents
  - paper
  - rayon
  - drains

Sodium chloride

- neutral salt of a strong acid and strong base
- ionic
- iodized against goiter
- $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ (warm); $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$ (strong heat)
- $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$

- molten: $2NaCl \rightarrow 2Na + Cl_2$; brine: $2NaCl + 2H_2O \rightarrow 2NaOH + H_2 + Cl_2$
- Solvay: $NaCl + NH_3 + CO_2 + H_2O \rightarrow NaHCO_3 + NH_4Cl$; $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$
- uses
  - food
  - pickles
  - oral rehydration solution
  - raw material

10.2 Alloys

- usually
  - harder
  - stronger
  - more corrosion resistant
  - lower melting
- different-sized atoms upset the rows, which slide less easily
- **substitutional**: about the same size, take places (brass: Zn 134 pm, Cu 128 pm)
- **interstitial**: much smaller, in gaps (steel: C 77 pm, Fe 126 pm)

Alloy	Made of	Used for, because
steel	Fe + up to about 2% C	buildings; more C harder, brittle
stainless	Fe + $\geq$10.5% Cr (18/8: 18 Cr, 8 Ni)	utensils; oxide film heals
invar	Fe + 36% Ni	clocks; hardly expands
alnico	Fe, Al, Ni, Co	strong magnets
brass	Cu + Zn, about 2 : 1	gagri, taps
bronze	Cu + Sn	statues, medals
bell metal	78% Cu, 22% Sn	bells, kansa; rings
gunmetal	Cu, 8–10% Sn, 2–4% Zn	valves, gears
German silver	60% Cu, 20% Ni, 20% Zn	cutlery; no silver
duralumin	Al, about 4% Cu, Mg, Mn	aircraft; light, strong
magnalium	Al + Mg	aircraft parts, balance beams
solder	63% Sn, 37% Pb	joints; melts about 183 °C
nichrome	80% Ni, 20% Cr	heating coils; high resistance, no oxidizing
dental amalgam	Hg + Ag, Sn, Cu	teeth; soft, then sets hard

- **ferrous**: iron the main metal
- **non-ferrous**: not
- **amalgams**: mercury
- iron and platinum form none, so mercury goes in iron flasks

COMMON MISTAKES

✗ Fe + HCl gives $FeCl_3$
✓ $FeCl_2$; chlorine gas gives $FeCl_3$.

✗ dry chlorine bleaches
✓ only moist: it needs HOCl.

✗ MnO_2 among the reactants
✓ over the arrow; not used up.

✗ a catalyst makes more product
✓ only faster.

✗ longer fizz means more gas
✓ a slower reaction.

✗ dry HCl gas is an acid
✓ only in water.

✗ copper reacts with dilute HCl
✓ below hydrogen; no reaction.

✗ steel is a compound
✓ a mixture: an alloy.

✗ German silver has silver
✓ Cu, Ni, Zn.