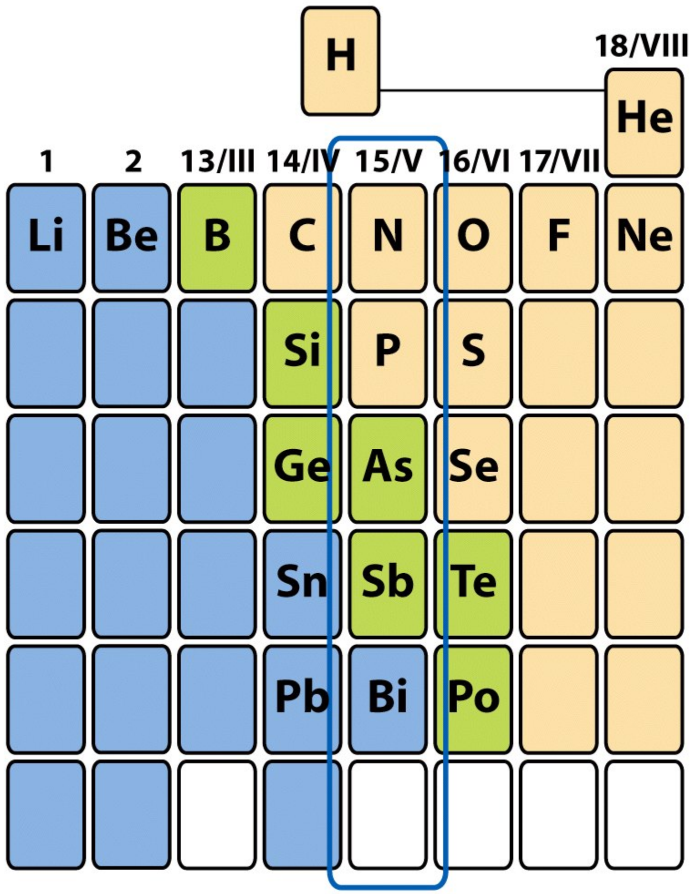
Chapter 15 - The Elements: The Last Four Main Groups

- Group 15/V: The Nitrogen Family
- Group 16/VI: The Oxygen Family
- Group 17/VII: The Halogens
- Group 18/VIII: The Nobel gases

Group 15: The Nitrogen Family

The Element



- Electron configurations ns^2np^3 (n is the period number)
- Oxidation states that range from -3 to +5
- The metallic character of the group increases down the group

Group 15: The Nitrogen Family

The Element (Nitrogen)

- Rare in the Earth's crust but elemental nitrogen (N_2) is the principal component of our atmosphere (76% by mass)
- $N \equiv N$ triple bond strength is 944 $kJ \cdot mol^{-1}$ making it almost as inert as the noble gases
- Nitrogen is used in medicines, fertilizers, explosives, and plastics
- The biggest commercial use for elemental nitrogen gas is for the formation of ammonia in the Haber process
- N is very electronegative and it is the only group 15 element that can form hydrides capable of hydrogen bonding
- N has a wide range of oxidation numbers. Nitrogen compounds are known to have every whole number oxidation number from -3 to +5. In addition, some fractional oxidation numbers are known to exists.
- N can only form up to four bonds

Group 15: The Nitrogen Family

The Element (Phosphorus)

- The radius of phosphorus is nearly 50% bigger than that of nitrogen. Thus P is too big to approach each other close enough for their 3*p* orbitals to overlap and form π bonds
- The availability of the 3*d* orbitals means that phosphorus can form as many as six bonds
- Condensed phosphorus vapor is called white phosphorus and is a soft, white, poisonous, molecular solid consisting of tetrahedral P_4 molecules.
- White phosphorus is highly reactive due to strain in its bonding angles and burst into flame when exposed to air
- White phosphorus changes to red phosphorus (amorphous network) when heated in the absence of air. Red phosphorus is much less reactive
- Red phosphorus is used in the striking surfaces of matchbook because the phosphorus ignites with friction

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

NH_3 (ammonia)

Properties:

Pungent

Toxic

Gas

Condenses to clear liquid at -33°C

- NH_3 is a reasonably strong Lewis base
- NH_3 salts decompose when heated
- The pungent smell of decomposing ammonium carbonate ($(NH_4)_2CO_3$) once made it an effective "smelling salt"

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

NH_4NO_3 (ammonium nitrate)

- Nitrate anion can oxidize the ammonium cation (products are temperature dependent).

$$NH_4NO_3(s) \xrightarrow{250^\circ C} N_2O(g) + 2H_2O(g)$$
$$2NH_4NO_3(s) \xrightarrow{>300^\circ C} 2N_2(g) + O_2(g) + 4H_2O$$

- The higher temperature reaction has explosive power and that is the reason that NH_4NO_3 is used as a component of dynamite
- Plants need nitrogen to grow but the N_2 is so stable that the plants can not break the triple bond to be able to utilize the nitrogen. NH_4NO_3 has a high concentration of N and dissolves in water there fore it is used as a fertilizer.

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

NH_2NH_2 (hydrazine)

Properties:

- Oily
- Colorless
- Liquid
- Dangerous Explosive

Uses:

- Rocket Fuel
- Remove dissolved corrosive oxygen from water

$$N_2H_4(aq) + O_2(g) \rightarrow N_2(g) + 2H_2O(l)$$

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

Nitrides (solids that contain the nitride ion N^{3-})

- Nitrides are only stable for small cations such as lithium or magnesium

Example:
Mg_3N_2

- Most nitrides dissolve in water to produce ammonia and the corresponding hydroxide

Example:
$Mg_3N_2(s) + 6H_2O(l) \rightarrow 3Mg(OH)_2(s) + 2NH_3(g)$

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

N_3^- (azide ion)

- Highly reactive polyatomic anion
- Its most common salt is sodium azide (NaN_3)
- Like most of the azide salts, NaN_3 it is shock sensitive
- NaN_3 is used in airbags where it decomposes to elemental sodium and nitrogen when detonated

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

- The azide ion is a weak base and accepts a proton to from its conjugate acid, hydrazoic acid (HN_3) which is a weak acid

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

PH_3 (phosphine)

Properties:

Poisonous Gas

Smells faintly of garlic

Burst into flame in air if it is slightly impure

- The nitrogen hydrogen compounds are much more stable that all of the other hydrogen compounds formed by the members of Group 15
- PH_3 is much less soluble than ammonia in water because PH_3 can not form hydrogen bonds to water
- Aqueous solutions of PH_3 are neutral because the electronegativity of phosphorus is so low that the lone pair of electrons on PH_3 is spread over the hydrogen atoms as well as the phosphorus atom
- PH_3 is a very weak acid

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

- A typical reaction of nonmetal halides, is their reaction with water to give oxoacids (an acid that contains oxygen), without a change in the oxidation number of the nonmetal that it is bonded to

Example:

$PCl_3(l) + 3H_2O(l) \rightarrow H_3PO_3(s) + 3HCl$

- This reaction is also an example of a hydrolysis reaction (a reaction with water in which new element-oxygen bonds are formed)

Group 15: The Nitrogen Family

Nitrogen Oxide and Oxoacids

TABLE 15.2 The Oxides and Oxoacids of Nitrogen

Oxidation number	Oxide formula	Oxide name	Oxoacid formula	Oxoacid name
5	N_2O_5	dinitrogen pentoxide	HNO_3	nitric acid
4	NO_2*	nitrogen dioxide	—	
	N_2O_4	dinitrogen tetroxide	—	
3	N_2O_3	dinitrogen trioxide	HNO_2	nitrous acid
2	NO	nitrogen monoxide nitric oxide	—	
1	N_2O	dinitrogen monoxide nitrous oxide	$H_2N_2O_2$	hyponitrous acid

*$2\ NO_2 \rightleftharpoons N_2O_4$.

- All nitrogen oxides are acidic
- Some are acid anhydrides (a compound that forms an oxoacid when it reacts with water)
- In atmospheric chemistry where the oxides play an important two edged role in both maintaining and polluting the atmosphere they are referred to collectively as NO_x (read "nox")

Group 15: The Nitrogen Family

Nitrogen Oxides and Oxoacids

N_2O (dinitrogen oxide)

Properties:

- Tasteless
- Unreactive
- Nontoxic in small amounts
- Soluble in fat

Uses:

Foaming agent and propellant for whipped cream

Group 15: The Nitrogen Family

Nitrogen Oxides and Oxoacids

NO (nitrogen oxide, nitrogen monoxide, or nitric oxide)

- NO (which is produced from hot airplane and automobile engines) has many harmful effects: leads to acid rain, formation of smog, as well as contributes to the destruction of the ozone layer
- NO is rapidly oxidized to NO_2 on exposure to air

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

- The NO_2 then reacts with water, forming acid rain
- NO also plays beneficial roles in small amounts. In the body it acts as a neurotransmitter and helps to dilate blood vessels and participates in other physiological changes

Group 15: The Nitrogen Family

Nitrogen Oxides and Oxoacids

NO_2 (nitrogen dioxide)

- Brown poisonous gas that contributes to the color and odor of smog
- The molecule has a odd number of electrons and in the gas phase it exist in equilibrium with its colorless dimer N_2O_4
- NO_2 dissolves in water to form nitric acid and nitrogen oxide which is what leads to acid rain

$$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$$

- NO_2 also initiates a complex sequence of smog forming photochemical reactions

Group 15: The Nitrogen Family

Nitrogen Oxides and Oxoacids

N_2O_3 (dinitrogen trioxide)

Properties:

Blue

Gas

- Is the anhydride of nitrous acid (HNO_2)

$$N_2O_3(g) + H_2O(l) \rightarrow 2HNO_2(aq)$$

Group 15: The Nitrogen Family

Compounds with Hydrogen and the Halogens

Nitrites (compounds that contain NO_2^-)

- Nitrites are produced by the reduction of nitrates (compounds with NO_3^-) with hot metal

Example:

$$KNO_3(s) + Pb(s) \xrightarrow{350^\circ C} KNO_2(s) + PbO(s)$$

- Most nitrites are mildly toxic

Uses:

Processing of meat products because they retard bacterial growth. They are responsible for the pink color of ham, sausage and other cured meats.

Group 15: The Nitrogen Family

Nitrogen Oxides and Oxoacids

HNO_3 (Nitric acid)

- HNO_3 is used in the production of fertilizers and explosives
- It is both an acid and an oxidizing agent
- It is made in the three-step Ostwald process

STEP 1: Oxidation of ammonia

$$4NH_3(g) + 5O_2(g) \xrightarrow{850^\circ C, 5atm, Pt/Rh} 4NO(g) + 6H_2O(g)$$

STEP 2: Oxidation of nitrogen oxide

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

STEP 3: Disproportionation (single atom is both oxidized and reduced) in water;

$$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$$

Group 15: The Nitrogen Family

Phosphorus Oxides and Oxoacids

- Oxoacids and oxoanions of phosphorous are among the most heavily manufactured chemicals.
- Phosphate fertilizer production consumes two-thirds of all the sulfuric acid produced in the United States
- The structures of the phosphorus oxides are based on the tetrahedral PO_4 unit

Group 15: The Nitrogen Family

Phosphorus Oxides and Oxoacids

H_3PO_4 (phosphoric acid)

- Used primarily for the production of fertilizer, food additives, and detergent
- Many soft drinks owe their tart taste to the presence of a small amount of phosphoric acid
- Although the phosphorus in H_3PO_4 has an oxidation number of +5 the acid shows appreciable oxidizing power at temperatures above 350°C

Group 15: The Nitrogen Family

Phosphorus Oxides and Oxoacids

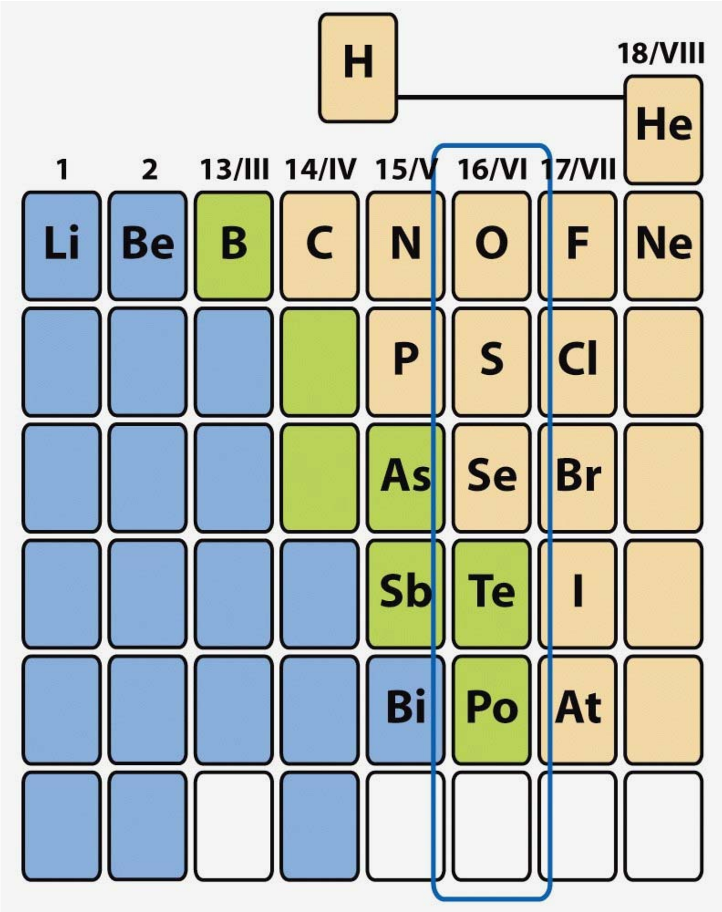
Phosphates (compounds contain PO_4^{3-})

- Phosphate rock is mined in huge quantities in Florida and Morocco
- The rock is crushed and treated with sulfuric acid to give a mixture of sulfates and phosphates called superphosphates, a major fertilizer

$$Ca_3(PO_4)_2(s) + 2H_2SO_4(l) \rightarrow 2CaSO_4(s) + Ca(H_2PO_4)_2(s)$$

Group 16: The Oxygen Family

The Element



- Electron configurations ns^2np^4 (n is the period number)
- Elements become increasingly more nonmetallic toward the right-hand side of the periodic table
- The elements of the group are collectively called the chalcogens

Group 16: The Oxygen Family

The Elements (Oxygen)

- Oxygen is the most abundant element in the Earth's crust
- The free element accounts for 23% of the mass of the atmosphere

Properties:

Colorless
Tasteless
Odorless
Condenses to a pale blue liquid

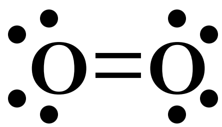
- Earth is the only planet in the solar system with an oxidizing atmosphere
- Oxygen is much more reactive than nitrogen the other major components of our atmosphere
- The combustion of all living organisms in oxygen is thermodynamically spontaneous however we do not burst into flame at normal temperature because combustion has a high activation energy

Group 16: The Oxygen Family

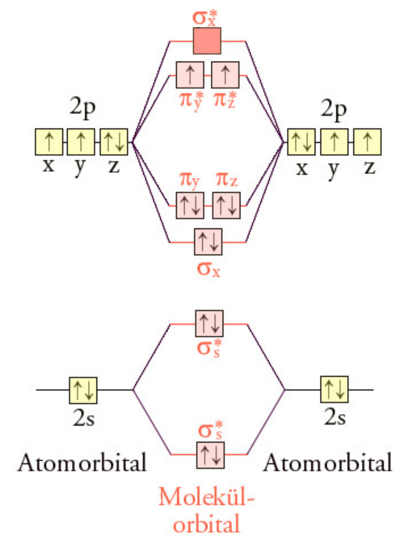
The Elements (Oxygen)

- The most common form of elemental oxygen is O_2.

Lewis Structure



Molecular Orbital Diagram



- O_2 has been shown to be paramagnetic therefore it behaves like the molecular orbital diagram predicts instead of the Lewis structure

Group 16: The Oxygen Family

The Elements (Oxygen)

- More than 2×10^{10} kg of liquid oxygen are produced in the United States a a year
- Liquid oxygen is produced by the fractional distillation of liquid air
- The biggest consumer of oxygen is the steel industry which needs about 1 t of oxygen to produce 1 t of steel.
- In steelmaking, oxygen is blown into molten iron to oxidize any impurities, particularly carbon
- O_2 is also used for welding and in medicine

Group 16: The Oxygen Family

The Elements (Oxygen)

O_3 (ozone)

Properties:
Blue gas
Condenses at -112°C

- O_3 is formed in the stratosphere by the effects of solar radiation on O_2 molecules
- O_3 can be made in the laboratory by passing an electric discharge through O_2
- O_3 is present in smog where it is produced by the following reaction

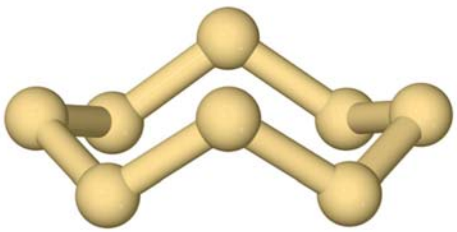
$O(g) + O_2(g) \rightarrow O_3(g)$

Note the O(g) is produced by $NO_2(g) \xrightarrow{UV radiation} NO(g) + O(g)$

Group 16: The Oxygen Family

The Elements (Sulfur)

- Sulfur behaves differently than oxygen due to its increased size and decreased electronegativity
- O can form H bonds while sulfur cannot
- Sulfur also has weaker tendencies to form multiple bonds to one atom
- Instead it can extend its octet by using its *d* orbitals and form as many as six bonds to separate atoms
- Sulfur has a striking ability to catenate, or forms chains of atoms. Oxygen's ability to form chains is limited



9 Sulfur, S_8

Group 16: The Oxygen Family

The Elements (Sulfur)

- Sulfur is found in many types of ores
- Because the ores are so common, sulfur is usually obtained as a by-product of the extraction of a number of metals (most notably Cu)
- Sulfur is also found as deposits of the native element called brimstone
- Sulfur has a low melting point
- To extract the sulfur a process called the Frasch process is used
- The Frasch process entails using super heated water to melt the solid sulfur and then uses compressed air to push the resulting slurry out

Uses:

Most sulfur is used to make sulfuric acid

The other largest use of sulfur is to vulcanize rubber

Group 16: The Oxygen Family

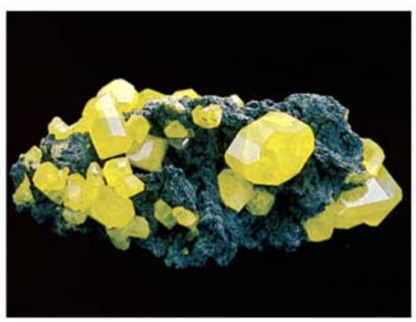
The Elements (Sulfur)

- Two common crystal forms of elemental sulfur are monoclinic
  ($a \neq b \neq c$ and $\alpha \neq 90$ $\beta = \gamma = 90$)
  and rhombic
  ($a = b = c$ and $\alpha \neq 90^{o}$, $\beta \neq 90^{o}$, $\gamma \neq 90^{o}$)
- The most stable form under normal conditions is rhomic sulfur which forms a beautiful yellow crystal

Properties:

Yellow
Tasteless
Almost Odorless
Insoluble
Nonmetallic

Rhomic Sulfur



Monoclinic Sulfur

Group 16: The Oxygen Family

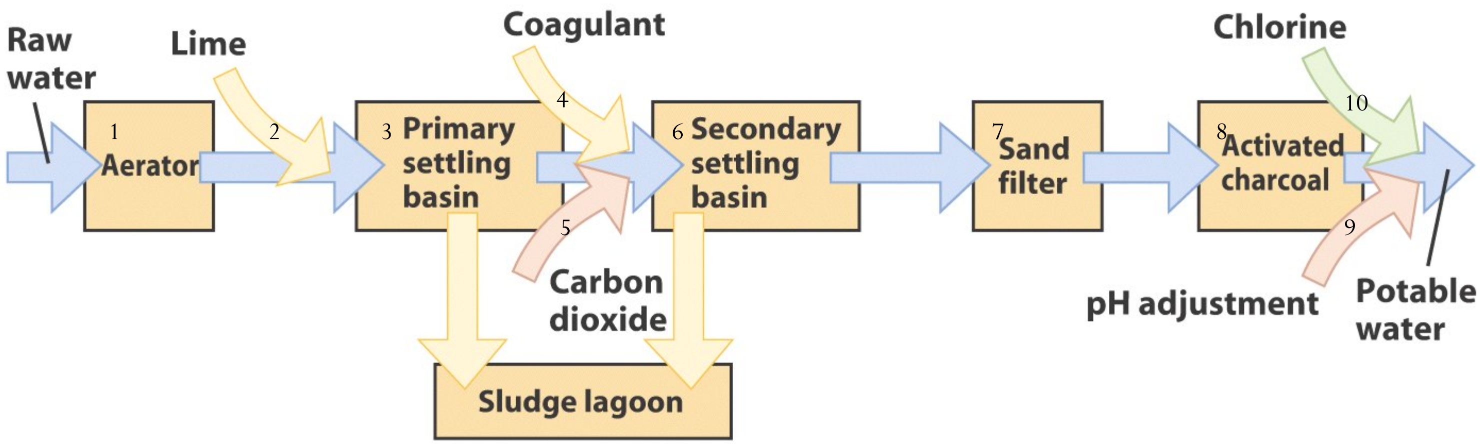
The Elements (Selenium and Tellurium)

- Selenium and tellurium occur in sulfide ores
- They are also recovered from the refining of copper
- Both elements have several allotropes with the most stable consisting of long zigzag chains of atoms
- These allotropes look like silver white metals however they are poor electrical conductors
- The conductivity of selenium is increased by exposure to light and so it is used in solar cells, photoelectric devices, and photocopying machines

Group 16: The Oxygen Family

Compounds with Hydrogen (Oxygen)

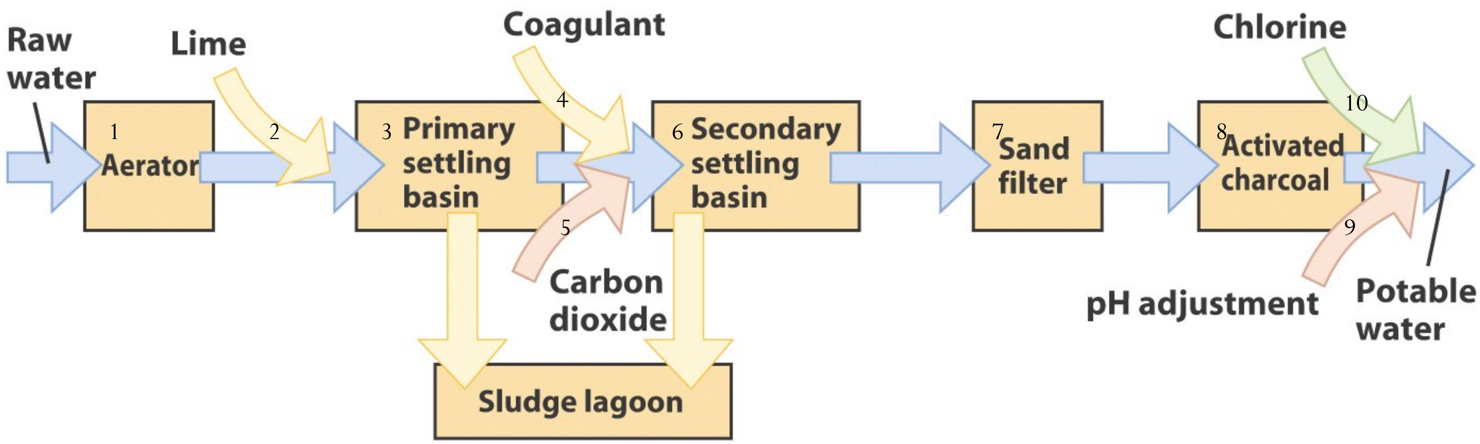
- The most important compound of O and H is water, H_2O
- Multiple steps are performed to purify our drinking water



1. Aerating is bubbling air through the water to remove any foul-smelling dissolved gases such as H_2S and organic compounds
2. Slaked lime ($Ca(OH)_2$) is added to reduce the acidity and precipitates Mg^{2+}, Fe^{3+}, Cu^{2+}, and other metal ions
3. The precipitate tends to form as a colloid (a very fine powder that remains suspended in the water)

Group 16: The Oxygen Family

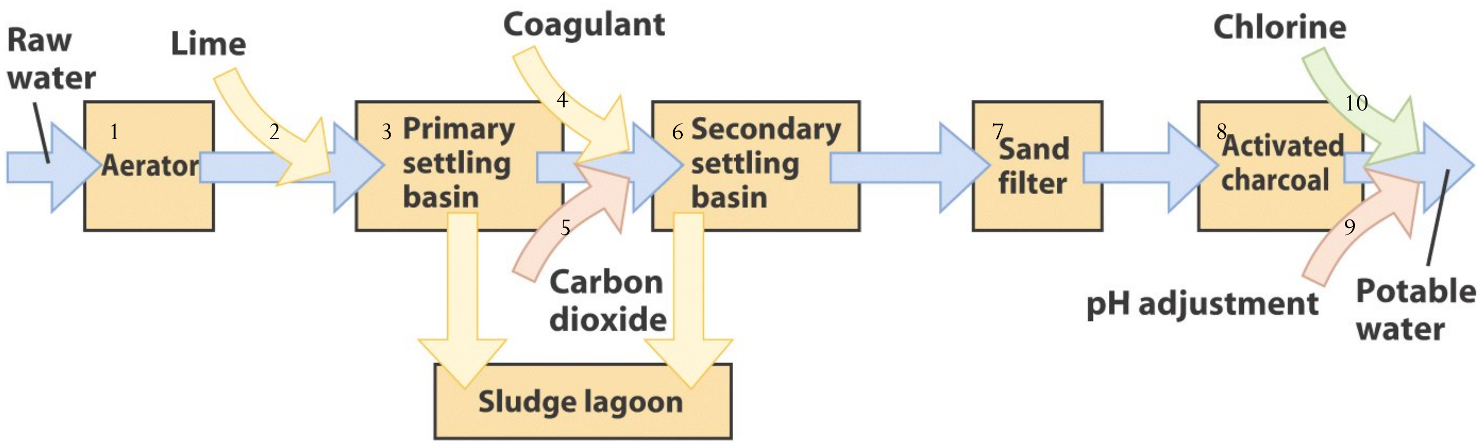
Compounds with Hydrogen (Oxygen)



4. $Fe_2(SO_4)_3$ or alum ($Al_2(SO_4)\cdot 18H_2O$) is added to coagulate (aggregation of smaller particles into a large one) or flocculate (the loose aggregation of particles to form a fluffy gel) the precipitates so that it can be filtered out
5. CO_2 is added to raise the acidity and promote the precipitation of aluminum as $Al(OH)_3$ so that it can be removed through filtration
6. Secondary settling basin
7. The water goes through sand to remove any particles that did not settle out

Group 16: The Oxygen Family

Compounds with Hydrogen (Oxygen)



8. The water then goes through activated charcoal to remove any organic compounds left in the water
9. The pH of the water is checked again and made slightly basic to reduce acid corrosion of the pipes
10. Chlorine is added as a disinfectant. Law requires that the chlorine level is greater than 1 g of Cl_2 per 1000 kg of water at the point of consumption. Note in water Cl_2 forms hypochlorous acid (HClO) which is highly toxic to bacteria

Group 16: The Oxygen Family

Compounds with Hydrogen (Oxygen)

- Often time we forget that water is reactive compound that is considered aggressively corrosive
- H_2O is an oxidizing agent

$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2(g)$ E = -0.42 V at pH = 7

- H_2O is also a mild reducing agent

$4H^+(aq) + O_2(g) + 4e^- \rightarrow 2H_2O(l)$ E = 0.82 V at pH = 7

- H_2O is a Lewis base (an electron pair donor)

Example:
Water donates 1 of its lone pair electrons to form complexes such as $Fe(H_2O)_6^{3+}$

Group 16: The Oxygen Family

Compounds with Hydrogen (Oxygen)

H_2O_2 (Hydrogen Peroxide)

Properties:

Pale blue liquid

Denser than H_2O

But has similar melting and boiling points to H_2O

- The presence of the second oxygen atom in H_2O_2 as apposed to H_2O makes H_2O_2 a very weak acid ($pK_{a1} = 11.75$)
- H_2O_2 is also a stronger oxidizing agent than water
- It can also act as a reducing agent in the presence of more powerful oxidizing agents
- H_2O_2 is sold for industrial uses as a 30% by mass aqueous solution
- A 6% H_2O_2 solution acts to oxidize the pigments in hair in order to bleach it
- A 3% H_2O_2 solution acts a a mild antiseptic

Group 16: The Oxygen Family

Compounds with Hydrogen

- Except for H_2O all the other Group 16 binary compounds with hydrogen (H_2E where E is a group 16 element) are toxic gases with offensive odors
- They are insidious poisons because they paralyze the olfactory nerve and soon after exposure the victim cannot smell them

Example:

Hydrogen sulfide (H_2S) smells like rotten eggs because egg proteins contain sulfur and eggs give off the gas when they decompose

Group 16: The Oxygen Family

Sulfur Oxides and Oxoacids

- Sulfur forms several oxides that in atmospheric chemistry are referred to collectively as SO_x (read “sox”)

Properties:

Gas

Colorless

Choking

Poisonous

SO_2 (Sulfur dioxide)

- Sulfur burns in air to form SO_2

Where the SO_2 in our air comes from

- $\sim 7\times10^{10}$ kg decomposition of vegetation and volcanic emissions
- $\sim 1\times10^{11}$ kg naturally occurring H_2S which is oxidized to SO_2 by O
- $\sim 1.5\times10^{11}$ kg industry and transportation (Electricity Plants)

Group 16: The Oxygen Family

Sulfur Oxides and Oxoacids

SO_2 (Sulfur dioxide)

Uses:

Refrigerant, preserve dried fruit, bleach for textiles and flour, producing sulfuric acid

- The oxidation number of sulfur in sulfur dioxide is +4 an intermediate in sulfurs range from -2 to +6
- Sulfur can act as either oxidizing agents or an reducing agent
- SO_2 is the starting material for making sulfur trioxide

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

- The SO_3 is then used to make sulfuric acid

Group 16: The Oxygen Family

Sulfur Oxides and Oxoacids

H_2SO_4 (Sulfuric acid)

Properties:

Colorless

Corrosive

Oily liquid

- It can be produced very cheaply
- H_2SO_4 is the most heavily produced inorganic chemical worldwide

Uses:

It is widely used in industry for the production of fertilizers, petrochemicals, and detergents

- About 2/3 of the sulfuric acid produced goes into manufacturing phosphate and ammonium sulfate fertilizers
- Three important chemical properties of H_2SO_4 are that it is a strong Bronstead acid (proton donor), a dehydrating agent, and an oxidizing agent

Group 16: The Oxygen Family

Demo

H_2SO_4 (Sulfuric acid)

- The powerful dehydrating ability of sulfuric acid can be seen when a little concentrated acid is poured on sucrose ($C_{12}H_{22}O_{11}$)

$$C_{12}H_{22}O_{11}(s) \rightarrow 12C(s) + 11H_2O(g)$$

- CO and CO_2 generated in a side reaction cause the froth

Group 16: The Oxygen Family

Sulfur Halides

- Sulfur reacts directly with all the halogens except iodine

SF_6 (Sulfur hexafloride)

- Sulfur reacts spontaneously in fluorine and burns brightly to give SF_6
- Despite its high oxidation number (+6), it is not a good oxidizing agent
- It is a good insulator in air and is used in switches on high-voltage power lines

Properties:

Dense
Colorless
Odorless
Thermally stable
Nontoxic gas

Group 16: The Oxygen Family

Sulfur Halides

S_2Cl_2 (disulfur dicholride)

Properties:
Yellow
Liquid
Nauseating Smell

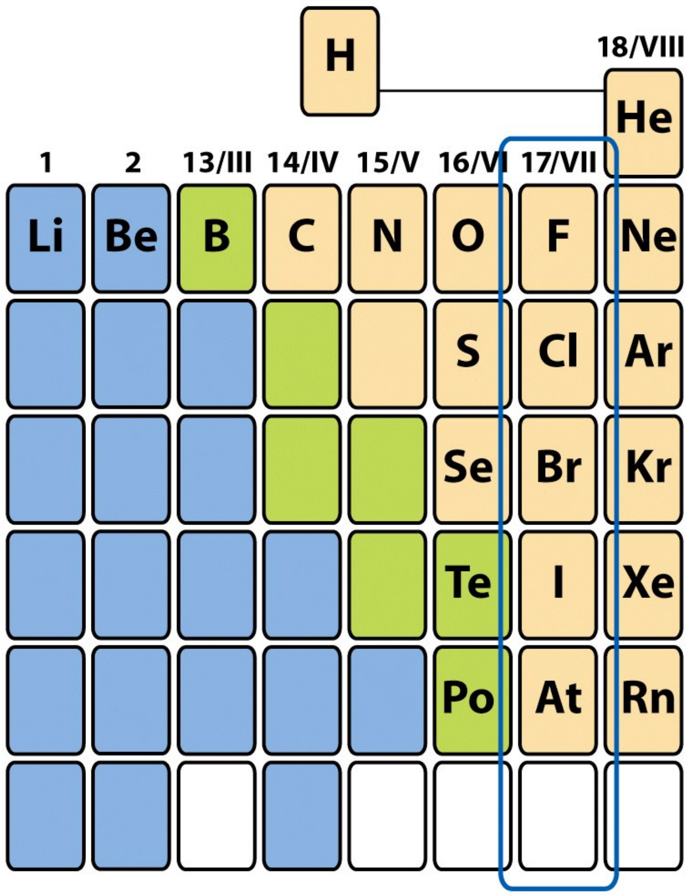
- S_2Cl_2 is one of the products of the reaction of sulfur with chlorine

Uses:
Vulcanization of rubber

- When S_2Cl_2 reacts with ethene (C_2H_4), mustard gas is formed which has been used in chemical warfare

Group 17: The Halogens

The Element



- Electron configurations ns^2np^5 (n is the period number)
- In its elemental state, all halogens atoms combine to form diatomic molecules (ex F_2,I_2,…)
- With the exception of F, the halogens can also lose valence electrons and their oxidation states can range from -1 to +7

Group 17: The Halogens

The Elements (Fluorine)

Properties:
Colorless
Gas

- Fluorine is the halogen with greatest abundance in the Earth's crust
- It occurs widely in many minerals
- Fluorine is the most strongly oxidizing element. Therefore, it cannot be obtained from its compounds by oxidation with another element
- Fluorine is produced by electrolyzing an anhydrous molten mixture of potassium fluoride and hydrogen fluoride at about 75°C with a carbon anode
- Most of the F produced by industry is used to make the volatile solid UF_6 used for processing nuclear fuel
- The next biggest user of F is the production of SF_6 for electrical equipment

Group 17: The Halogens

The Elements (Fluorine)

- Is the most electronegative element
- It has an oxidation number of -1 in all its compounds
- The high electronegativity and small size (it allows for several F atoms to pack around a central atom) allow it to oxide other elements to their highest oxidation number
- F is less soluble than other halides

Group 17: The Halogens

The Elements (Chlorine)

Properties:
Pale yellow
Gas

- Chlorine is more soluble in water than fluorine
- As a result even though there is more F present in the Earth's crust the oceans are salty with chlorides rather than fluorides
- Cl is one of the most heavily manufactured chemicals
- It is obtained from electrolysis of molten rock salt (NaCl) or brine
- Cl will directly react with nearly all the elements except for C, N,O and the noble gases
- It is a strong oxidizing agent

Uses: In a number of industrial processes, including the manufacture of plastics, solvents, and pesticides. It is also used as bleach in the paper and textile industries and as a disinfectant in water treatment plants. In addition, Cl is used to produce Br

Group 17: The Halogens

The Elements (Bromine)

Uses:

Br is used widely in synthetic organic chemistry because of the ease at which it can be added to and removed from organic chemicals that are being used to carry out complicated syntheses. Organic bromides are incorporated into textiles as fire retardants and are used as pesticides. Inorganic bromides, particularly silver bromide, are used in photographic emulsions

Properties:

Corrosive

Red-Brown

Liquid

Group 17: The Halogens

The Elements (Iodine)

- When iodine dissolves in organic solvents it produces solutions having a variety of colors
- These colors arise from the different interaction between the I_2 molecules and the solvent
- Iodine is an essential trace element for living systems; a deficiency in humans leads to a swelling of the thyroid gland in the neck
- Iodides are added to table salt (iodized salt) to prevent this deficiency

Group 17: The Halogens

Compounds of the Halogens

- The halogens form compounds among themselves. These interhalogens have the formulas XX', XX'_3, XX'_5, and XX'_7 (X heavier halogen)
- These compounds are prepared by direct reaction of the two halogens, the product formed being determined by the proportions of the reactants used

Example:

$Cl_2(g) + 3F_2(g) \rightarrow 2ClF_3(g)$

$Cl_2(g) + 5F_2(g) \rightarrow 2ClF_5(g)$

- The trends of the interhalogens are intermediate between those of their parent halogens

TABLE 15.5 Known Interhalogens

Interhalogen	Normal form*
XF_n	
ClF	colorless gas
ClF_3	colorless gas
ClF_5	colorless gas
BrF	pale-brown gas
BrF_3	pale-yellow liquid
BrF_5	colorless liquid
IF	unstable
IF_3	yellow solid
IF_5	colorless liquid
IF_7	colorless gas
XCl_n	
BrCl	red-brown gas
ICl	red solid
I_2Cl_6	yellow solid
XBr_n	
IBr	black solid

**Normal form* means the appearance and state of the compound at 25°C and 1 atm.

Group 17: The Halogens

Compounds of the Halogens (Hydrogen Halides)

- The hydrogen halides (HX) can be prepared by the direct reaction of the elements.

Example:
$H_2(g) + X_2(g) \rightarrow 2HX(g)$

- Fluorine reacts explosively by a radical chain reaction as soon as the F_2 and H_2 are mixed
- The mixture of H_2 and Cl_2 explodes when it is exposed to light
- Br_2 and I_2 react much more slowly
- Another way to produce the hydrogen halides is the reaction of a metal halide with a nonvolatile acid

Example:
$CaF_2(s) + 2H_2SO_4(aq, conc) \rightarrow Ca(HSO_4)_2(aq) + 2HF(g)$

Group 17: The Halogens

Compounds of the Halogens (Hydrogen Halides)

- All the hydrogen halides are colorless, pungent gases except HF which is a liquid at temperature below 20°C
- HF is significantly different that the other hydrogen halides because it can form short zigzag chains up to 5 HF molecules long. These chains are sustained due to H bonding networks
- All hydrogen halides dissolve in water to give acidic solutions
- HF has the distinctive property of attacking glass and silica and the interiors of lamp bulbs are frosted by the vapors from a solution of HF and ammonium fluoride
- HF is also used for making fluorinated carbon compounds such as Teflon

Group 17: The Halogens

Compounds of the Halogens (Oxoacids)

- The acid strengths and the oxidizing ability of the halogen oxoacids increase with the oxidation number of the halogens
- Hypohalous acids (HXO note +1 oxidation number) are prepared by direct reaction of the halogen with water

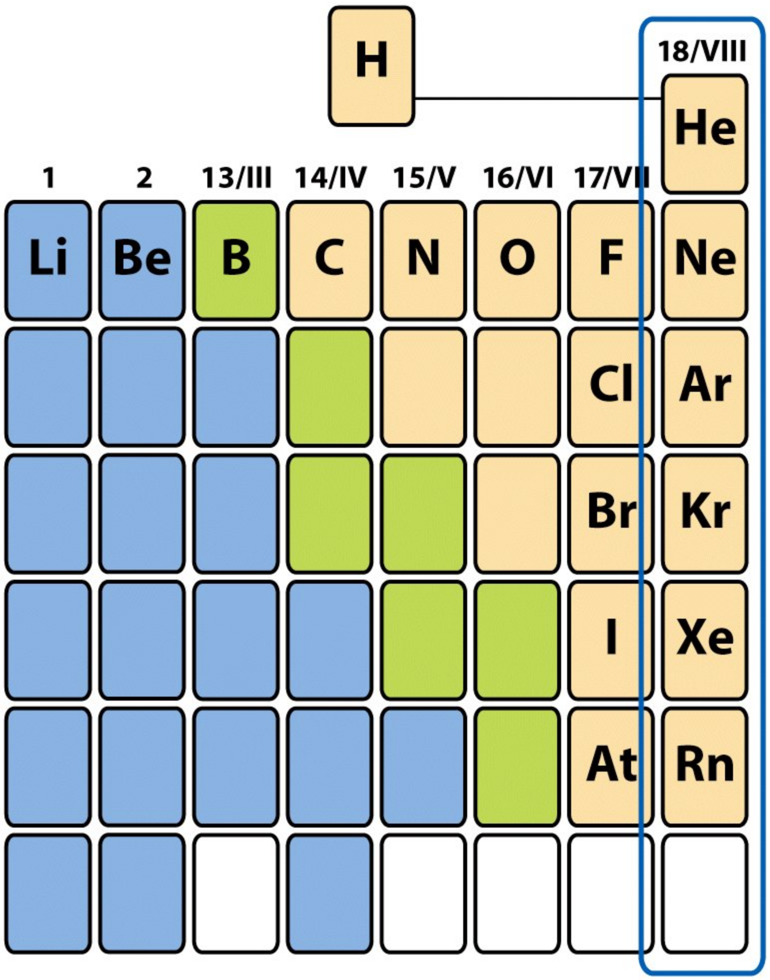
Example:

$Cl_2(g) + H_2O(g) \rightarrow HClO(g) + HCl$

- Hypohalite ions (XO^-) are formed when a halogen is added to the aqueous solution of a base
- Calcium hypochlorite ($Ca(ClO)_2$) is used to chlorinate swimming pools because when placed in the pool it forms Ca^{2+} ions which form insoluble calcium carbonate which can be removed through filter systems
- Because hypochlorites (HClO) oxidize organic material they are used in liquid household bleaches and as disinfectants

Group 18: The Nobel gases

The Elements



- Electron configurations ns^2np^6 (n is the period number)
- Their closed shell electron configuration makes them have a very low reactivity

Group 18: The Nobel gases

The Elements

- All the noble gases occur in the atmosphere as monatomic gases.
- Together they make up 1% (by mass) of the atmosphere
- Argon is the third most abundant gas in the atmosphere after nitrogen and oxygen
- All of the noble gases except He and Rn are obtained by the fractional distillation of liquid air

Group 18: The Nobel gases

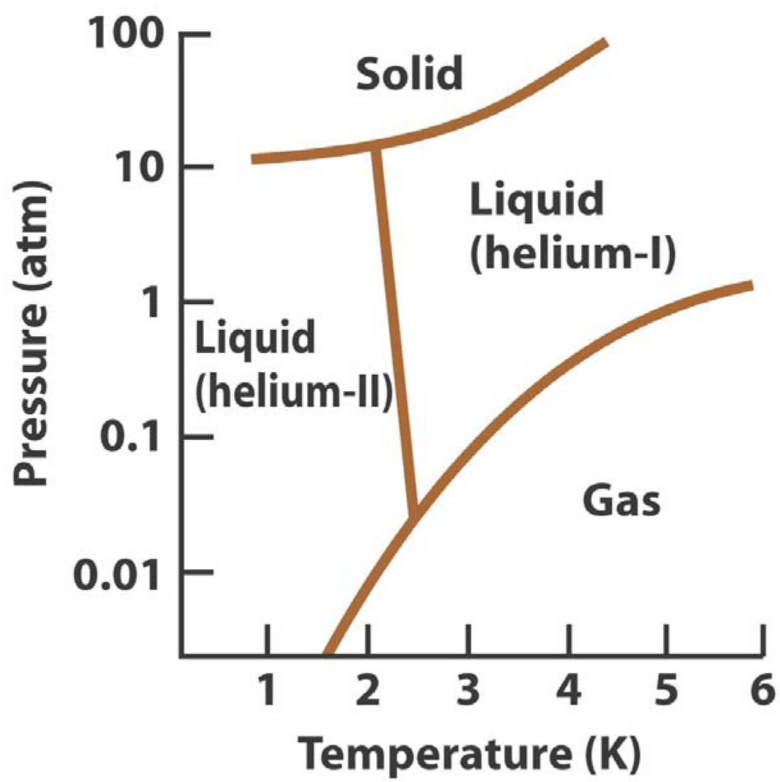
The Elements (Helium)

- Helium is the second most abundant element in the universe after hydrogen
- However it is rare on earth because it is so light that it can reach the high speeds needed to escape from the atmosphere
- However unlike hydrogen, helium can not be anchored to compounds. Therefore is less common the hydrogen on earth
- Helium is found as a component of natural gases trapped under rock formations where it has collected as a result of the emission of α particles by radioactive elements
- Helium gas is twice as dense as hydrogen under the same conditions
- Its density is still very low and it is nonflammable therefore it is used to provide buoyancy in blimps

Group 18: The Nobel Gases

The Elements (Helium)

- Helium is the only substance known to have more than one liquid phase
- Below 2 K liquid helium-II shows the remarkable property of superfluidity (the ability to flow without viscosity i.e. has no resistance to flow)



Group 18: The Nobel Gases

The Elements

- Neon glows orange-red when an electrical current is passed through it and is used for advertising sings and displays
- Argon is used to provide an inert atmosphere for welding to prevent oxidation
- Argon is also used to fill some types of light bulbs, where it conducts heat away from the filament
- Krypton gives an intense white light when an electrical current is passed through it and it is used in airports for there runway lights
- Krypton is produced by nuclear fission, its atmospheric abundance is one measure of worldwide nuclear activity
- Xeon is used in halogen lamps, for automobile headlights, and in high speed photographic flash tubes
- Radon is a radioactive gas that seeps out of the ground and its presence can lead to dangerously high levels of radiation

Group 18: The Nobel Gases

Compounds of the Nobel Gases

- The ionization energies of the noble gases are very high but decrease down the group
- No compounds of helium, neon, or argon exist except under very special conditions
- Krypton forms only one known stable neutral molecule KrF_2
- Xenon’s ionization energy is low enough for electrons to be lost to very electronegative elements
- Xe forms several compounds with fluorine and oxygen and compounds with Xe-N and Xe-C bonds have been reported
- Xenon fluorides are used as powerful fluorinating agents (reagents for attaching fluorine atoms to other substances)