

NONMETALS and THEIR COMPOUNDS

Carbon C
Nitrogen N
Oxygen O
Phosphorus P
Sulfur S
Halogens F Cl Br I
Hydrogen H



12 NONMETALS
Oxygen **O**. Sulfur **S**. Nitrogen **N**. Phosphorus **P** 3

13 ACIDIC OXIDES
Sulfur dioxide SO_2. Sulfur trioxide SO_3 13

14 ACIDS
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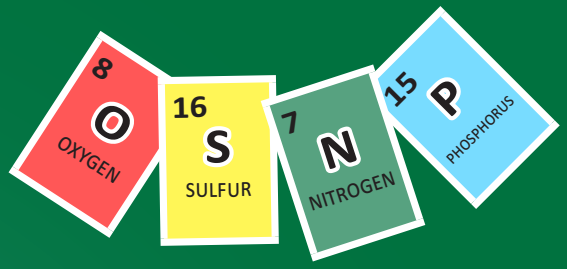
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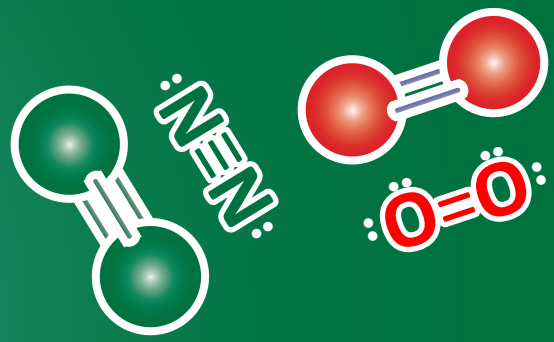
NONMETALS

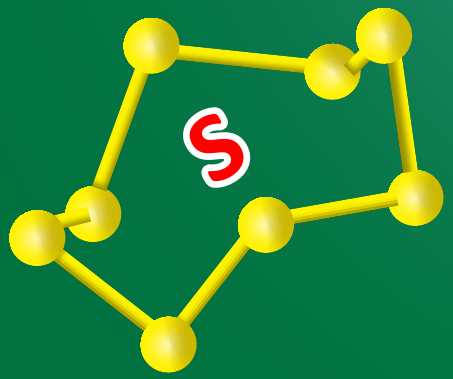
Oxygen O. Sulfur S. Nitrogen N. Phosphorus P

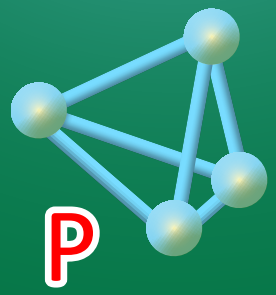


KEY TOPICS

1. What are nonmetals?
2. What is allotropy?
3. What are the simple substances of oxygen, sulfur, nitrogen and phosphorus?
4. How do nonmetals react?







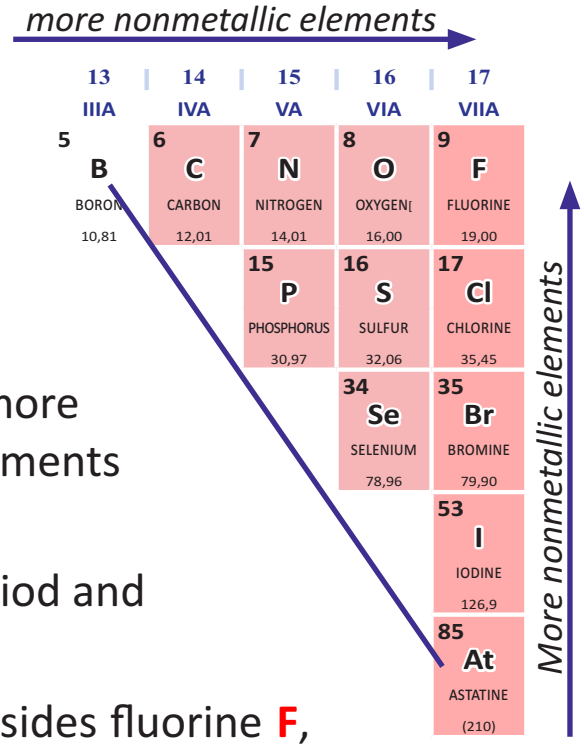
KEY WORDS

- Nonmetals
- Allotropy and Allotropic forms
- Oxygen and Ozone
- Rhombic and Monoclinic sulfur
- Red and White phosphorus
- Hydrogen sulfide
- Ammonia

WHAT ARE NONMETALS?

Generally, nonmetals are elements that *are not metals* (as suggests their name). Nonmetallic elements do not exhibit the properties of the metallic elements – they are insulators (electrical and thermal) and without the typical for all metals metallic lustre. Some are colourless, other are coloured, some are odourless, other – with specific odour. They may be solid or gaseous (only bromine Br is liquid), some of the solid nonmmetals are brittle. They also exhibit different chemical properties.

Nonmetals are much less than metals but they exhibit various properties.



In the periodic table the nonmetalic elements are located to the right of the virtual line linking Boron **B** and Astatine **At**.

Across a period the nonmetallic properties of the elements become more pronounced. Down a main group the nonmetallic character of the elements decreases.

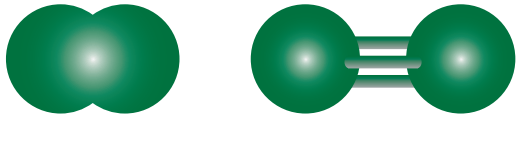
The most nonmetallic element is Fluorine **F**. It is located in the second period and 17 (VIIA) group.

Typical nonmetals are the halogens – the elements of 17 (VIIA) group (besides fluorine **F**, also chlorine **Cl**, bromine **Br** and iodine **I**). The other typical nonmetals are carbon **C** (14 (IVA) group), nitrogen **N** and phosphorus **P** (15 (VA) group), oxygen **O** and sulfur **S** (16 (VIA) group).

Hydrogen **H** is also considered as a nonmetallic element.

SIMPLE SUBSTANCES OF OXYGEN, SULFUR, NITROGEN and PHOSPHORUS. STRUCTURE and PHYSICAL PROPERTIES

OXYGEN and **NITROGEN** are period 2 elements. At STP* they are gases. Their molecules are diatomic: O_2 and N_2. Both molecules are nonpolar. The two oxygen atoms are linked by a double covalent bond, while the bond in the nitrogen molecule is triple and very strong. Three atoms of oxygen can also bond to form a stable triatomic molecule O_3. This simple substance of oxygen is *ozone.* Its molecules are very reactive.



N_2 $N \equiv N$

$:N \equiv N:$

Nitrogen molecule N_2

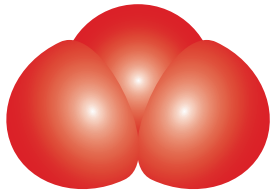


O_2 $O=O$

$:\ddot{O}=\ddot{O}:$

Oxygen molecule O_2

The property of some chemical elements to exist in two or more different forms is named ALLOTROPY.



Ozone molecule O_3

The different forms built up of the atoms of the same element are called allotropes or allotropic forms. Thus, oxygen O_2 and ozone O_3 are allotropes of oxygen O. The structure of the molecules is different and their properties are not the same – oxygen is a colourless, odourless and tasteless gas. Ozone is a pale blue gas with a specific sharp irritating odour. It is heavier than oxygen. The melting and the boiling points of the two allotropes of oxygen are different.

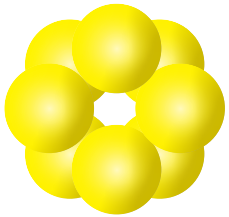
NITROGEN has no allotropes. It is a colourless, odourless, tasteless gas, slightly lighter than air.

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*__STP__ – __S__tandard __T__emperature 273,15 K (O °C) and __P__ressure 101 325 Pa

PHOSPHORUS and **SULFUR** are period 3 elements. They are solid with molecular or atomic structure. Both have allotropes.

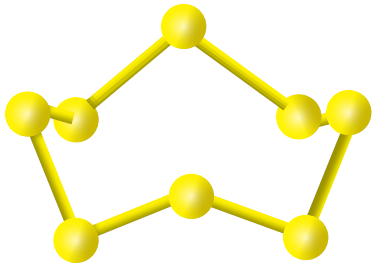
Sulfur is a yellow solid substance with molecular structure. It is insoluble in water. It has poor thermal conductivity and no electrical conductivity.

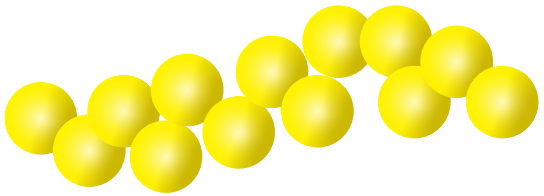


8-ATOMIC MOLECULE OF SULFUR S_8

Sulfur has three allotropes: crystalline –- rhombic and monoclinic, and amorphous.

Crystalline sulfur is built up of 8-atomic molecules. They form 3D puckered zigzag rings. The rhombic sulfur is brittle and can be ground into powder. The monoclinic crystals are almost colourless. They are stable at temperatures above 95,5 °C.

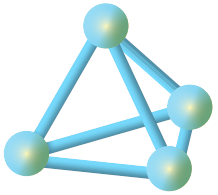




STRUCTURE OF PLASTIC SULFUR

Sulfur becomes plastic at temperatures above 120 °C – the 8-atomic rings are broken down and long zigzag chains of sulfur are formed. The plastic sulfur can be molded in different shapes.

Phosphorus is a solid substance at STP. It exists in many allotropes but the most known are white and red phosphorus.



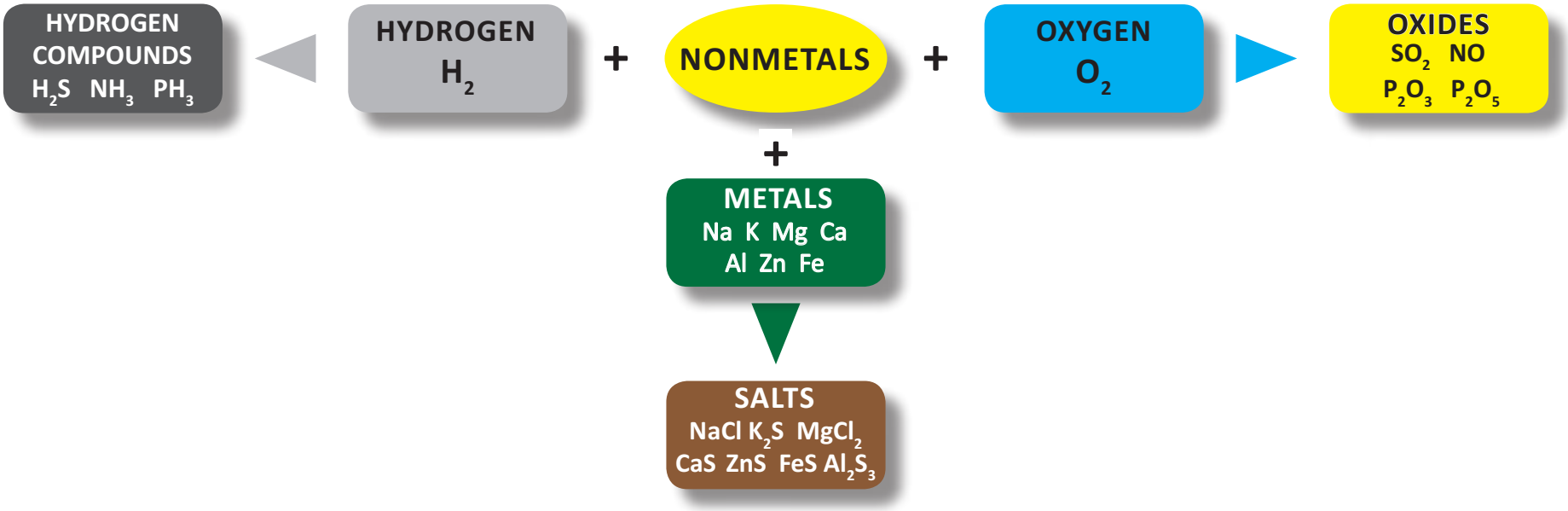
4-ATOMIC MOLECULE OF WHITE PHOSPHORUS P_4

The white phosphorus is built up of tetrahedral molecules of four phosphorus atoms bonded to each other by single covalent bonds. It is a pale yellow wax-like solid. It can inflame spontaneously upon exposure to air and must be stored under water. It is toxic. Red phosphorous is also built up of 4-atoms tetrahedral molecules but they are linked to form long chains. This make red phosphorous much less reactive than white phosphorus.

CHEMICAL PROPERTIES OF NONMETALS

Generally, nonmetals are active substances. Fluorine F_2 is the most active nonmetal.

Typical for nonmetals are the reactions with *hydrogen*, *oxygen* and *metals*. In all reactions the reactants are simple substances and the products – chemical compounds: *hydrogen compounds* H_2S, NH_3; *oxides* SO_2, NO; *salts* Na_2S, Al_2S_3, etc.:



REACTIONS WITH HYDROGEN H_2

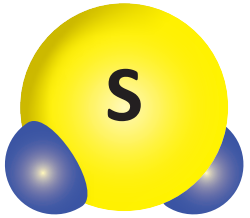
Nonmetals combine with hydrogen and form hydrogen compounds – for example H_2S, NH_3:

NONMETAL + H_2 → **HYDROGEN COMPOUND**

Sulfur combines with hydrogen under heating. The product is a colourless gas – dihydrogen sulfide **H_2S** (sulfur is divalent):

$$H_2 + S \xrightarrow{t^o} H_2S$$

Dihydrogen sulfide



Dihydrogen sulfide (commonly named hydrogen sulfide) is a colourless, flammable, corrosive and highly poisonous gas with a specific odour (of rotten eggs). Its toxicity is similar to carbon monoxide CO. Like hydrogen chloride HCl it dissolves in water and dissociates into positive hydrogen ions H^+ and negative sulfide ions S^{2-} – hydrosulfuric acid is formed:



HYDROGEN SULFIDE MOLECULE
H_2S

$$H_2S \xrightarrow{H_2O} 2H^+ + S^{2-}$$

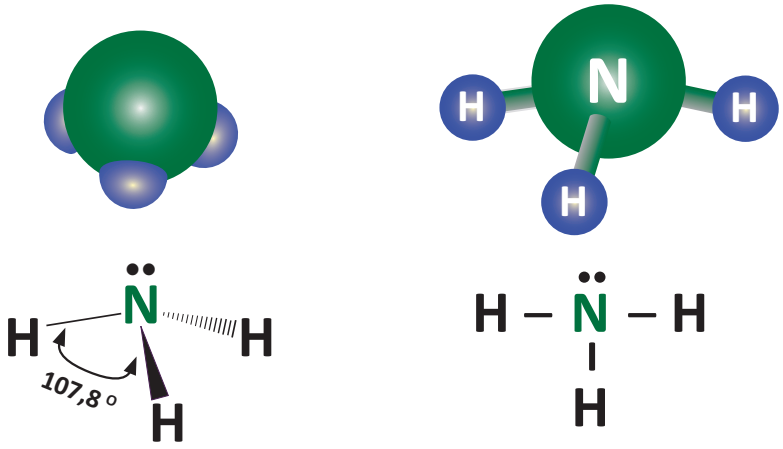
Dihydrogen sulfide — Hydrosulfuric acid

The blue litmus paper dipped in hydrosulfuric acid turns red as in all acidic solutions.

Nitrogen reacts with hydrogen. The product is *ammonia* (also named *azane)* NH_3:

$$N_2 + 3H_2 \rightleftarrows 2NH_3$$

Ammonia



AMMONIA MOLECULE

NH_3

The industrial production of ammonia undergoes at high temperature (about 450 °C) and high pressure (about 30 MPa (300 atmospheres)) and in the presence of a catalyst*.

In the ammonia molecule three hydrogen atoms are bonded by simple polar covalent bonds to the nitrogen atom. The molecule of NH_3 is polar and looks like a triangular pyramid.

Under standard conditions NH_3 is a colourless gas with a sharp pungent odour, lighter than air. In high concentrations it is very harmful. Ammonia is easily liquefied under pressure. When liquid ammonia evaporates it absorbs a large amount of heat – this explains its application as a cooling agent.

The aqueous solutions of ammonia unlike the solutions of H_2S and HCl manifest basic properties and change the colour of litmus into blue:

$$NH_3 + HOH \rightleftarrows \underset{\text{Ammonium hydroxide}}{NH_4OH} \rightleftarrows \underset{\text{Ammonium ion}}{NH_4^+} + \underset{\text{Hydroxide ion}}{OH^-}$$

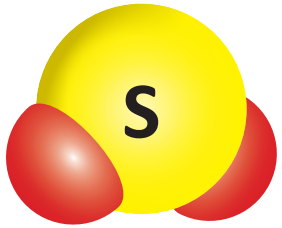
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*__Catalysts__ are substances that accelerate chemical reactions without themselves being consumed.

REACTIONS WITH OXYGEN O_2

Nonmetals react with oxygen at high temperatures and form oxideS:

NONMETAL + O_2 → **OXIDE**



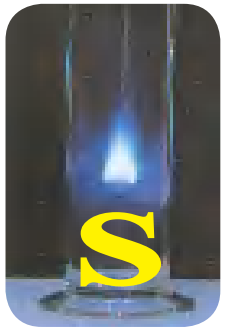
SULFUR DIOXIDE MOLECULE

SO_2

Sulfur burns with a blue flame at temperatures above 360 °C and forms a gas – sulfur dioxide **SO_2**:

$$S + O_2 \xrightarrow{t^o} SO_2$$

Sulfur dioxide



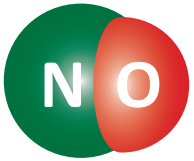
Sulfur burns
at a high temperature

In sulfur dioxide SO_2 sulfur S is tetravalent – one sulfur atom is bonded to two oxygen atoms.

Nitrogen does not react with oxygen at standard conditions. A reaction occurs only at very high temperatures or if an electric spark passes through the gas mixture (as in the atmosphere during lightning discharges). The product is a gas – nitrogen oxide **NO**:

$$N_2 + O_2 \rightleftarrows 2NO$$

Nitrogen oxide



NITROGEN OXIDE MOLECULE

NO

In nitrogen oxide NO nitrogen is divalent. Indirectly nitrogen forms other oxides in which it displays variable valences (from first to fifth): **N_2O N_2O_3 NO_2 N_2O_5.**

REACTIONS WITH METALS

Nonmetals combine with metals and form *salts* – NaCl, $CaCl_2$, CaS, MgS, etc.



Sulfur reacts with almost all metals. The products are salts named *sulfide* – FeS iron sulfide, Al_2S_3 dialuminum trisulfide, Na_2S disodium sulfde, CaS calcium sulfide, etc. In these compounds sulfur is divalent. For example:

$$Fe + S \xrightarrow{\text{heating}} FeS$$

Iron sulfide

Iron sulfide FeS is a shiny (like metals) substance. It is found in nature as a mineral.

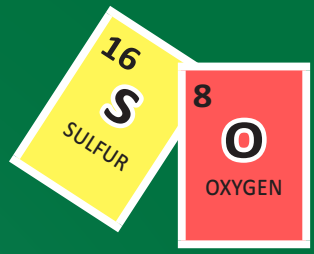
Most of *sulfides* are coloured solid substances, insoluble in water. Some of them are found in nature as minerals – for example galenite (PbS), sphalerite (ZnS), pyrite (FeS_2), etc. They are used to produce nonferrous metals.

CAN YOU ANSWER THESE QUESTIONS ?

1. Why are metals and nonmetals different classes of simple substances?
2. Why is fluorine the most nonmetallic element?
3. Why are nitrogen and oxygen gases at STP?
4. Is there just one simple substance of sulfur and of phosphorus? Why?
5. What are the typical for all nonmetals chemical reactions?
6. Water H_2O can be produced in a direct reaction of hydrogen and oxygen. But in the atmosphere oxygen and hydrogen exist as diatomic gases H_2 and O_2 without reacting to form water molecules. Why?
7. Hydrogen and oxygen are colourless and odourless gases. How could you distinguish between them?
8. Why is the water solution of hydrogen sulfide acidic?
9. What is ammonia?
10. Why are sulfur dioxide SO_2 and sulfur trioxide SO_3 different compounds?
11. What gas is produced in the direct reaction of nitrogen with oxygen?
12. How are sulfur salts named?

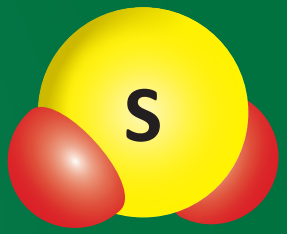
13 Acidic oxides.

Sulfur dioxide SO_2. Sulfur trioxide SO_3

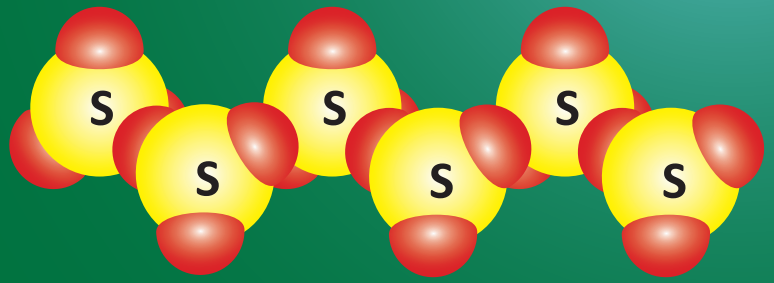


KEY TOPICS

1. What oxides are acidic?
2. What are their typical chemical reactions?
3. Why does sulfur form two different oxides – SO_2 and SO_3?
4. Why is sulfur trioxide SO_3 an acidic oxide?



SO_2



solid SO_3

KEY WORDS

- Acidic oxides
- Sulfur trioxide
- Sulfates
- Gypsum

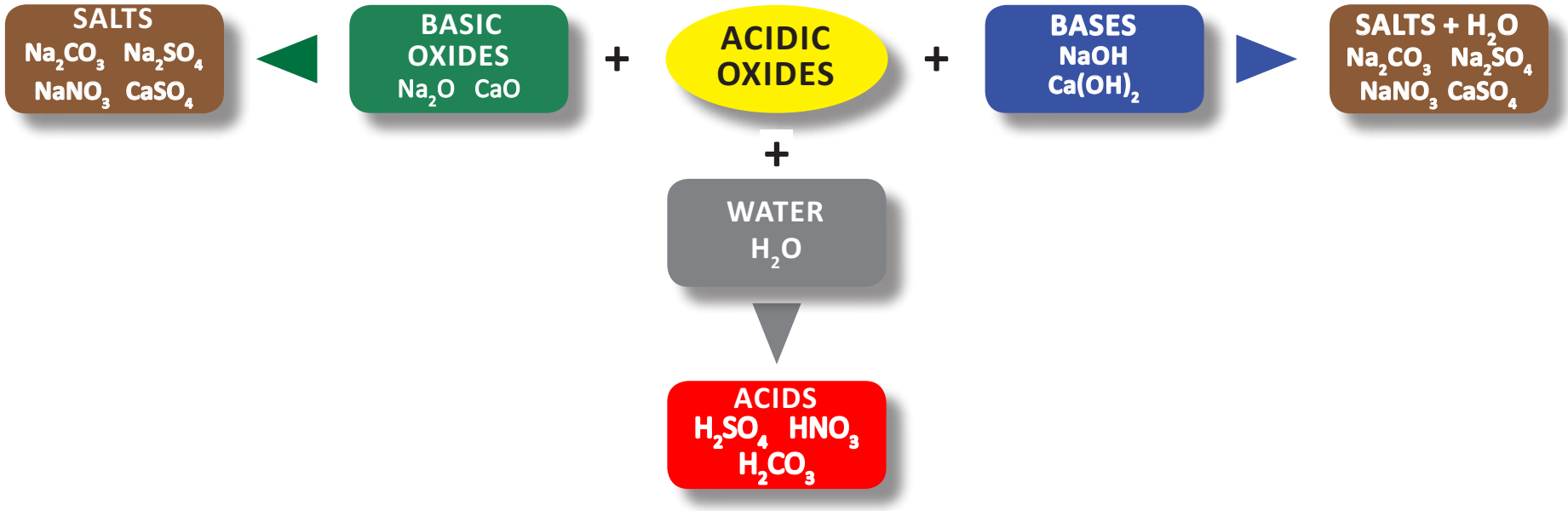
WHAT OXIDES ARE ACIDIC?

Most of the oxides of nonmetals react with water and form *acids*. That is the reason to name these oxides acidic oxides.

Typical acidic oxides are the oxides of sulfur SO_2 and SO_3, some of the oxides of nitrogen – N_2O_3, NO_2 N_2O_5, carbon dioxide CO_2, diphosphorus pentaoxide P_2O_5, etc. In these compounds oxygen is covalently bonded to atoms of nonmetals. The bond is more or less polar. As a hole the oxides molecules are polar (for examole SO_2) or nonpolar (for example CO_2).

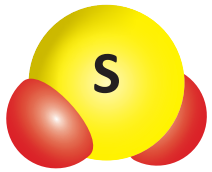
At STP some acidic oxides are gases (SO_2, CO_2) other are liquids (N_2O_3) or solids (SO_3, N_2O_5).

Acidic oxides are chemically active compounds. Besides the reaction with water typical are the interactions with *basic oxides* and *bases*. In both reactions the products are salts. In the reactions with bases water is also formed:



Sulfur dioxide SO_2. Sulfur trioxide SO_3

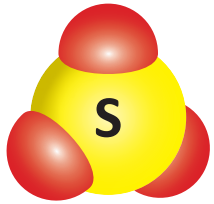
Sulfur dioxide **SO_2** is produced in the direct reaction of sulfur with oxygen. As the maximum valence of sulfur is 6th (it is located in VIA group and it has 6 electrons in its outermost electron shell)) it also forms another oxide – SO_3 sulfur trioxide. Under special conditions (at an elevated temperature and in the presence of a catalyst) sulfur dioxide SO_2 reacts with oxygen and transforms into sulfur trioxide SO_3:



SO_2

$$2SO_2 + O_2 \rightleftarrows 2SO_3$$

Sulfur dioxide — Sulfur trioxide

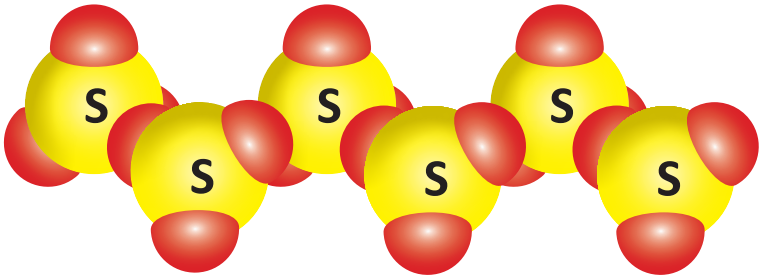


SO_3

Both oxides of sulfur are substances with molecular structure.

In the molecules of SO_2 sulfur is bonded by polar covalent bonds to two oxygen atoms. The SO_2 molecules ares polar. At STP SO_2 is a colourless gas with a specific pungent odour. It is poisonous and should not be inhaled.

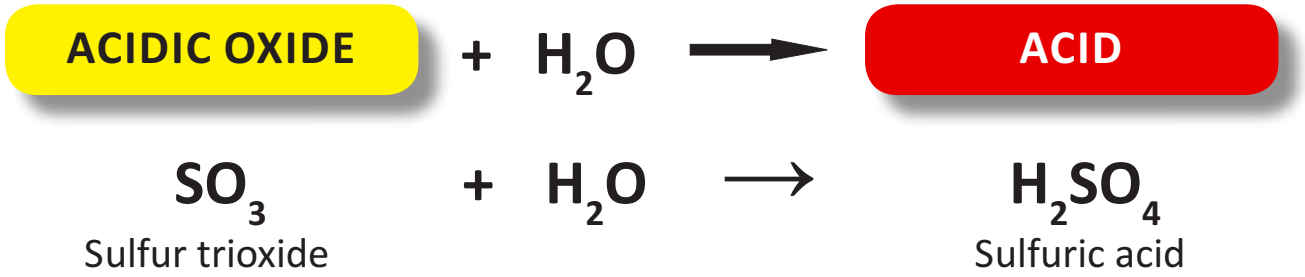
In the SO_3 molecules one sulfur atom is covalently bonded to three oxygen atoms. The bonds are polar. At a temperature below 16,8 °C sulfur trioxide SO_3 is a solid substance. Its molecules form rings or long chains. Between 16,8 °C and 45 °C sulfur trioxide SO_3 is a colourless liquid. At higher temperature it is in gaseous state. The molecules of the gaseous SO_3 are planar and nonpolar as the angle between the S–O bond is 120°.



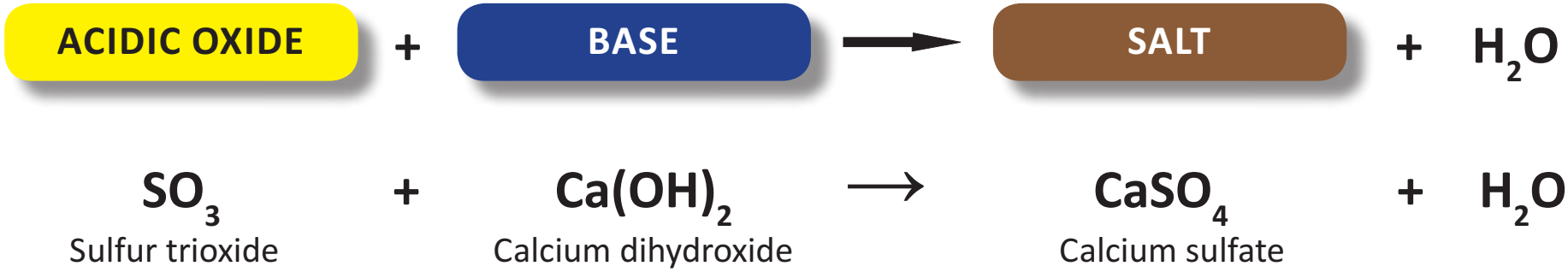
Solid sulfur trioxide **SO_3**

CHEMICAL PROPERTIES OF SULFUR TRIOXIDE SO_3

Sulfur trioxide SO_3 is a typical acidic oxide. It reacts with water, basic oxides and bases:







The salts are named sulfates. For exmple $CaSO_4$ – calcium sulfate. It is commonly known as *gypsum*.

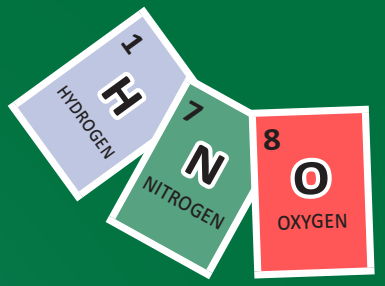
CAN YOU ANSWER THESE QUESTIONS ?

1. What oxides are acidic?
2. Are all acidic oxides gases?
3. Why does nitrogen form several acidic oxides?
4. What products are made in the reactions of acidic oxides with bases?
5. How is sulfur trioxide SO_3 produced?
6. What is the structure of the oxides of sulfur?
7. How to produce calcium sulfate?
8. What is the common name for $CaSO_4$?
9. Are sulfates ionic or molecular compounds?
10. What product is made in the reaction of sulfur trioxide SO_3 with water?

14 Acids

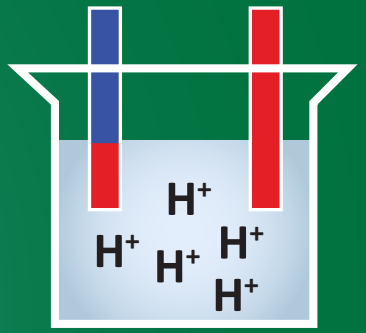
Sulfuric acid H_2SO_4. Nitric acid HNO_3

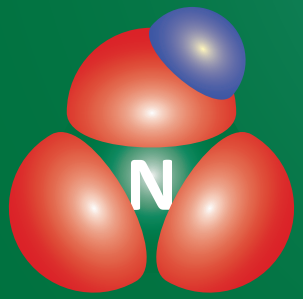




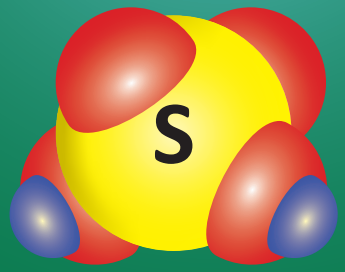
KEY TOPICS

1. What are acids?
2. Why do all acids manifest similar properties?
3. Why are concentrated sulfuric and nitric acids so harmful compounds?
4. How do acids react with metals and bases?





HNO_3

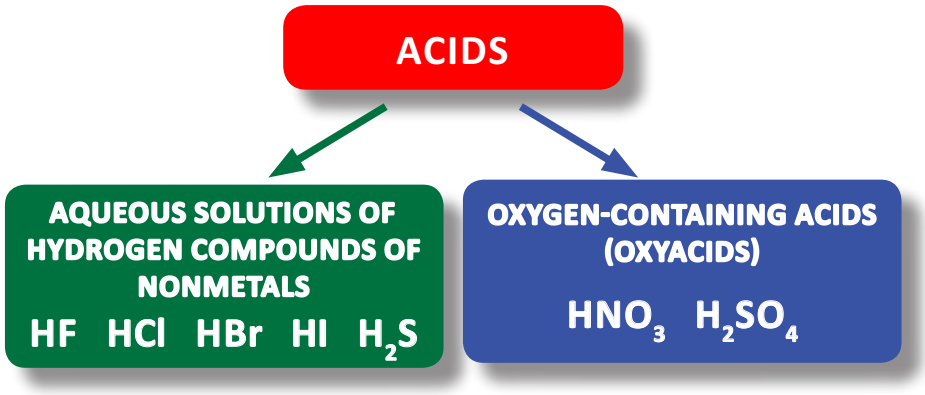


H_2SO_4

KEY WORDS

- Acids
- Dissociation
- Acidic ions
- Polyatomic ions
- pH
- Sulfuric acid
- Nitric acid
- Nitrates

WHAT ARE ACIDS?



ACIDS are chemical compounds made up of the atoms of two or three elements. One of the elements is always **hydrogen H**. The second element in the molecules of acids made up of only two elements is a nonmetallic element (fluorine F, chlorine, Cl, sulfur S, nitrogen N, phosphorus P, carbon C, etc.). If there is a third element building up the molecule of an acid, it is usually **oxygen O**. Thus, acids are classified as acids that do not contain oxygen – generally *aqueous solutions of hydrogen compounds of nonmetals* (for example HCl, H_2S) and *oxygen-containing acids* or *oxyacids* (for example nitric acid HNO_3, sulfuric acid H_2SO_4).

Acids dissociate in water releasing one or more hydrogen ions H^+ and simple (for example S^{2-}, Cl^-) or *polyatomic* (for example NO_3^-, SO_4^{2-}) negative ions called *acidic ions*:

$$\underset{\text{Hydrogen chloride}}{HCl\ (gas)} \xrightarrow{H_2O} \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Chloride ion}}{Cl^-}$$

$$\underset{\text{Sulfuric acid}}{H_2SO_4\ (liquid)} \xrightarrow{H_2O} \underset{\text{Hydrogen ion}}{2H^+} + \underset{\text{Sulfate ion}}{SO_4^{2-}}$$

The aqueous solution of hydrogen chloride HCl is known as hydrochloric acid.

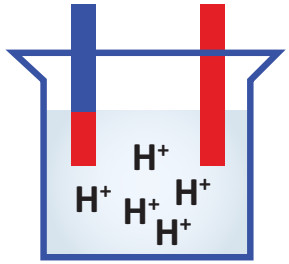
The liberated hydrogen ion H^+ bonds to a water molecule and forms a hydronium ion H_3O^+. Thus, the dissociation of hydrogen chloride in water may be also expressed as:

$$HCl + H_2O \rightarrow \underset{\text{Hydronium ion}}{H_3O^+} + Cl^-$$

Both chemical equations are correct.

ACIDS dissociate in water into positive hydrogen ions H^+ and negative acidic ions (for example Cl^-, S^{2-}, SO_4^{2-}, NO_3^-).

Hydrogen ions H^+ in aqueous solutions of acids are easily detected using litmus or phenolphthalein – litmus turns red and phenolphthalein is colourless.



Litmus paper turns red in aqueous solutions of acids

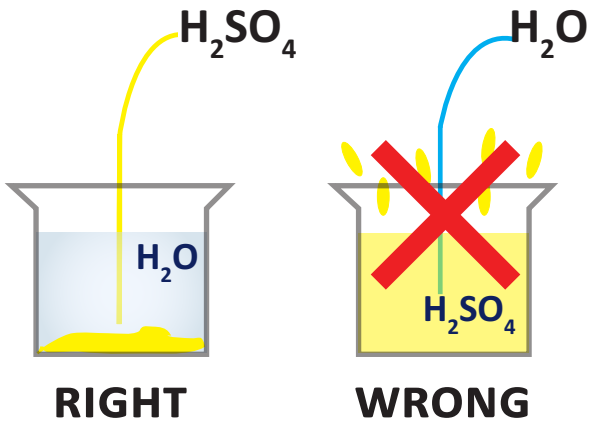
FOR ALL AQUEOUS SOLUTIONS OF ACIDS pH* < 7

Most of the acids are colourless liquids (H_2SO_4, H_2S, HCl). Some acids are solid at STP – for example boric acid H_3BO_3 is a white crystalline substance. Acids have a sour taste but most of them should be never tasted as they are very harmful substances.

Concentrated strong acids like H_2SO_4 and HNO_3 dissolve readily in water. Their dilution is accompanied by the release of a great amount of heat. The solution heats itself and may splash if water is added to the acid solution as water is lighter.

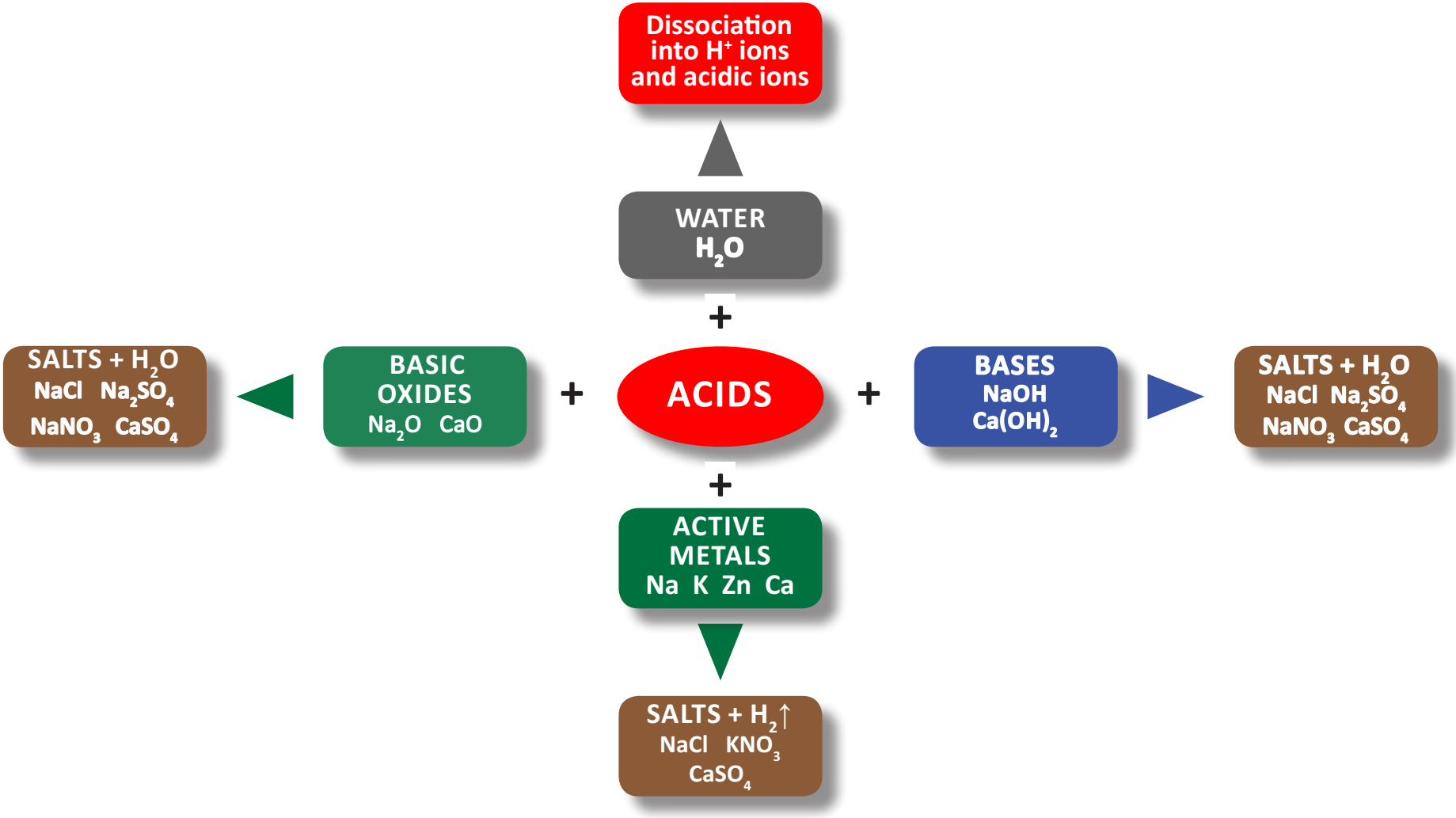
POUR THE ACID VERY SLOWLY IN A THIN STREAM INTO THE WATER!

If a drop of an acid gets on the skin it must be blotted with a filter paper and rinsed repeatedly with water. In case of serious burns a physician must be consulted as soon as possible.



*pH is a measure of the acidity or the basicity of the solutions – its value is related to the amount of H^+ ions in the solution.

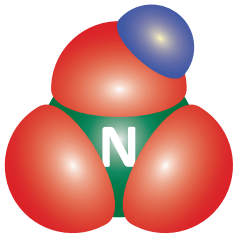
The common chemical properties of the aqueous solutions of acids are due to the highly reactive hydrogen ions. Besides the dissociation in water, typical for acids are the reactions with *active metals*, *basic oxides* and *bases*:



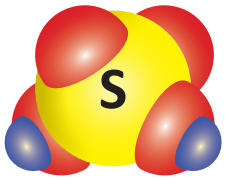
Sulfuric acid H_2SO_4. Nitric acid HNO_3.

Sulfuric acid **H_2SO_4** and nitric acid **HNO_3** are two of the most important chemical products. Both are oxyacids (they contain oxygen). The pure sulfuric acid is a colourless oily liquid. It fumes as traces of SO_3 are released. They immediately react with the water vapours in the air forming droplets of sulfuric acid. Nitric acid is also a colourless liquid with a specific sharp odour but often it is pale yellow as some amounts of nitrogen dioxide NO_2 dissolve in it.

The molecule of HNO_3 is built up of one nitrogen **N** atom covalently bonded to three oxygen atoms **O**. One of the oxygen atoms is covalently bonded to a hydrogen atom **H**. All bonds are polar.



Nitric acid molecule
HNO_3



Sulfuric acid molecule
H_2SO_4

In the molecule of H_2SO_4 one sulfur atom **S** is covalently bonded to four oxygen atoms **O.** **T**wo of the oxygen atoms are covalently bonded to hydrogen atoms **H**. All bonds are polar. More polar (as in HNO_3 molecules) are the oxygen – hydrogen bonds. They are easily broken down as compared to the oxygen – sulfur covalent bonds and H^+ ions are readily released in water media.

The concentrated nitric acid HNO_3 and the concentrated sulfuric acids H_2SO_4 manifest some specific properties as only a few of the acids molecules dissociate in water. So the amount of H^+ ions is to small. The concentrated nitric and sulfuric acids are toxic and extremely dangerous. They burn up the skin, the cloths, the plastics. When working with them it is obligatory to respect all recommended safety precautions – goggles and an apron are obligatory and protective gloves should be also used.



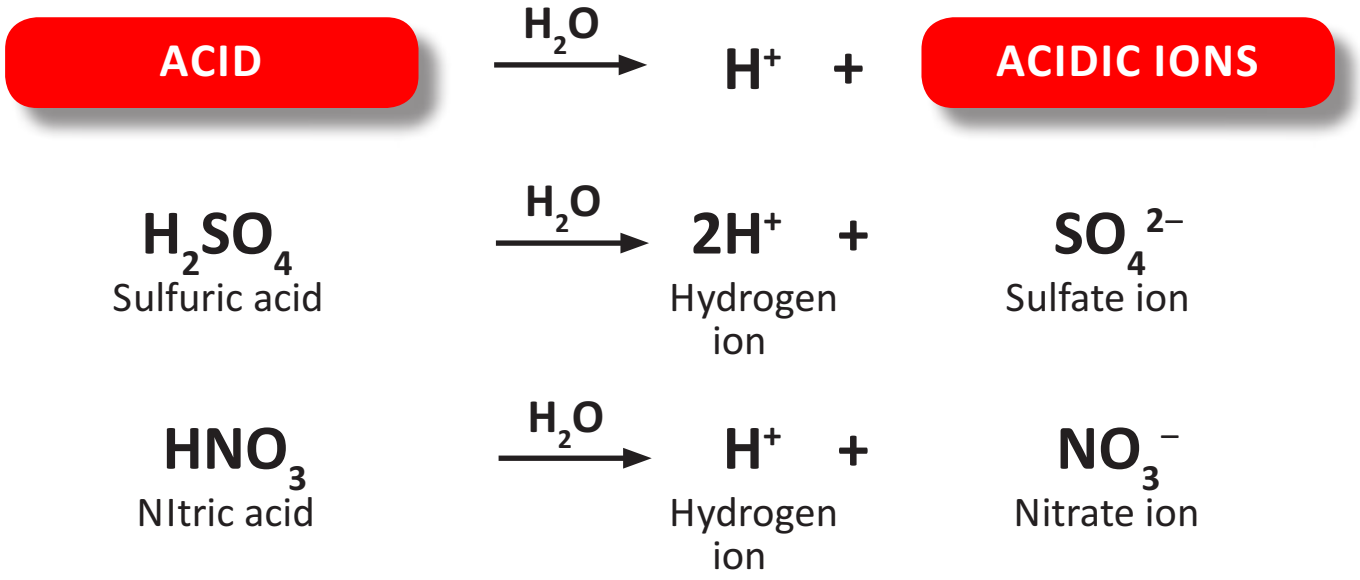
Safety symbols to indicate the necessary personal protection if working with concentrated strong acids

CHEMICAL PROPERTIES OF DILUTED SULFURIC H_2SO_4 and NITRIC HNO_3 ACIDS

As typical strong acids the diluted HNO_3 and H_2SO_4 dissociate in water and react with active metals, basic oxides and bases:

DISSOCIATION IN WATER

Both acids dissociate in water into positive hydrogen ions H^+ and negative acidic ions – sulfuric acid liberates SO_4^{2-} (sulphate) ions and nitric acid liberates NO_3^- (nitric) ions:



The chemical properties of diluted sulfuric acid H_2SO_4 and diluted nitric acid HNO_3 are similar as H^+ ions are present in the aqueous solutions of both acids.

REACTION WITH ACTIVE METALS

Active metals as the alkali (IA group) and alkaline earth metals (IIA group), also Zn, Fe and many others, react with both acids. If a piece for example of sodium Na is put in a solution of H_2SO_4 the metal disappears – It dissolves reacting with the H^+ ions of the dissociated acid and transforms into positive ions Na^+. In the same time bubbles of hydrogen H_2 rise in the solution and the gas is evolved in the air (in the chemical equation this is denoted by the symbol „↑“):

ACTIVE METAL + **ACID** → **SALT** + $H_2\uparrow$

or:

$$2Na + H_2SO_4 \longrightarrow Na_2SO_4 + H_2\uparrow$$

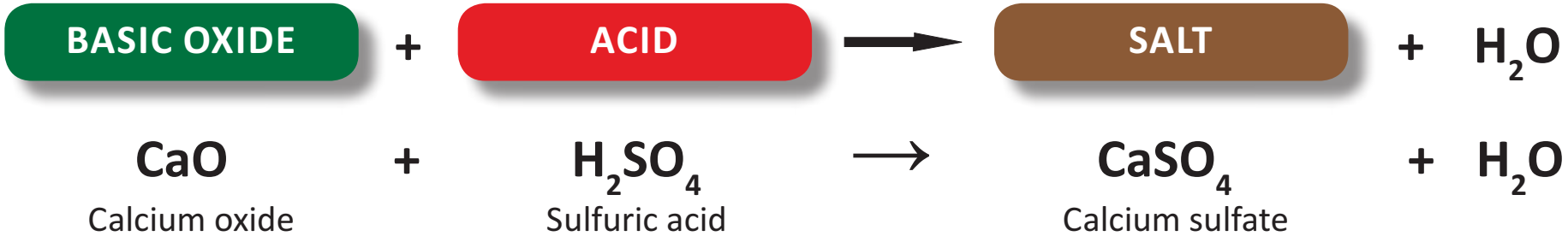
$$2Na + 2H^+ + SO_4^{2-} \longrightarrow 2Na^+ + SO_4^{2-} + H_2\uparrow$$

Sodium — Sulfuric acid — Disodium sulfate

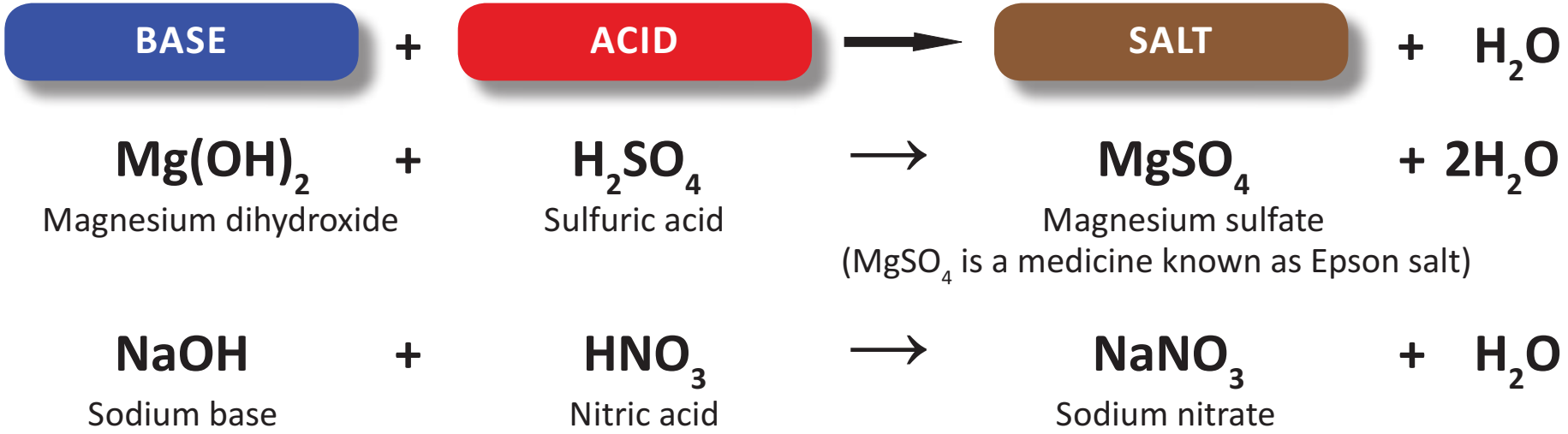
Copper, silver, gold, platinum can not displace the hydrogen ions in the aqueous solution of H_2SO_4 and HNO_3. The mixture of concentrated hydrochloric acid and concentrated nitric acid in a ratio 3:1 is known as „aqua regia“ and is used to dissolve gold, platinum and other less active metals.

REACTION WITH BASIC OXIDES AND BASES

Acids react with basic oxides (oxides of active metals) and the product is always a salt – for example $CaSO_4$ if sulfuric acid H_2SO_4 reacts with calcium oxide CaO:



The reaction of an acid with a base is called **NEUTRALIZATION**. The products are always a salt and water. For example:



Sulfates (for example Na_2SO_4 disodium sulfate, $CaSO_4$ calcium sulfate, $Al_2(SO_4)_3$ dialluminum trisulfate, $CuSO_4$ copper sulfate, etc.) are solid ionic compounds built up of metallic positive ions (Na^+, Ca^{2+}, Al^{3+}, Cu^{2+}) and negative sulfate ions SO_4^{2-}. Some of them are minerals – $CaSO_4$. $MgSO_4$, $FeSO_4$.

It is interesting to know:

SO_4^{2-} ions in a solution are easily detected with the reagent $BaCl_2$ barium dichloride. The salt barium sulfate $BaSO_4$ is insoluble in water. If $BaCl_2$ is added to a solution containing SO_4^{2-} ions a white precipitate of $BaSO_4$ is formed. For example:

$$H_2SO_4 + BaCl_2 \rightarrow BaSO_4\downarrow + 2HCl$$

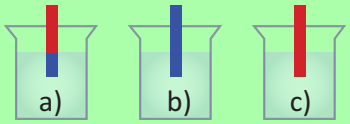
$$Na_2SO_4 + BaCl_2 \rightarrow BaSO_4\downarrow + 2NaCl$$

This is a test reaction for soluble sulfates. The symbol „↓“ is used to indicate the formation of a precipitate.

The salts of the nitric acid are called **nitrates**. They are crystalline substances, soluble in water. The nitrates of 1A and 2A group metals and of ammonia are called *saltpeters*: KNO_3 – potassium saltpeter, $NaNO_3$ – Chile saltpeter, NH_4NO_3-– ammonium saltpeter, $Ca(NO_3)_2$ – Norwegian saltpeter. This gives the Latin name *Nitrogenium* which means saltpeter-producing.

CAN YOU ANSWER THESE QUESTIONS ?

1. What are acids?
2. Why are acids a class of chemical compounds manifesting similar properties?
3. Are all compounds containing hydrogen acids?
4. What is an oxyacid?
5. Litmus papers are dipped in three beakers with solutions of unknown substances. Which is the solution of sulfuric acid?



6. Why do we always add acid to water but never water to acid?
7. Both NaOH and HNO_3 have a hydroxy group –OH. But in water HNO_3 dissociates liberating a H^+ ion unlike NaOH that liberates an OH^- ion. Why?
8. What is the pH of pure lemon jus? Greater or lower than 7?
9. Why are concentrated strong acids like H_2SO_4 and HNO_3 very harmful substances?
10. What happens if we put a piece of potassium in a solution of sulfuric acid?
11. What is neutralization?
12. What are the compounds **X** and **Z**?

$$Na + X \rightarrow Z + H_2\uparrow$$
$$Z + H_2SO_4 \rightarrow Na_2SO_4 + X$$
$$Z + HNO_3 \rightarrow NaNO_3 + X$$

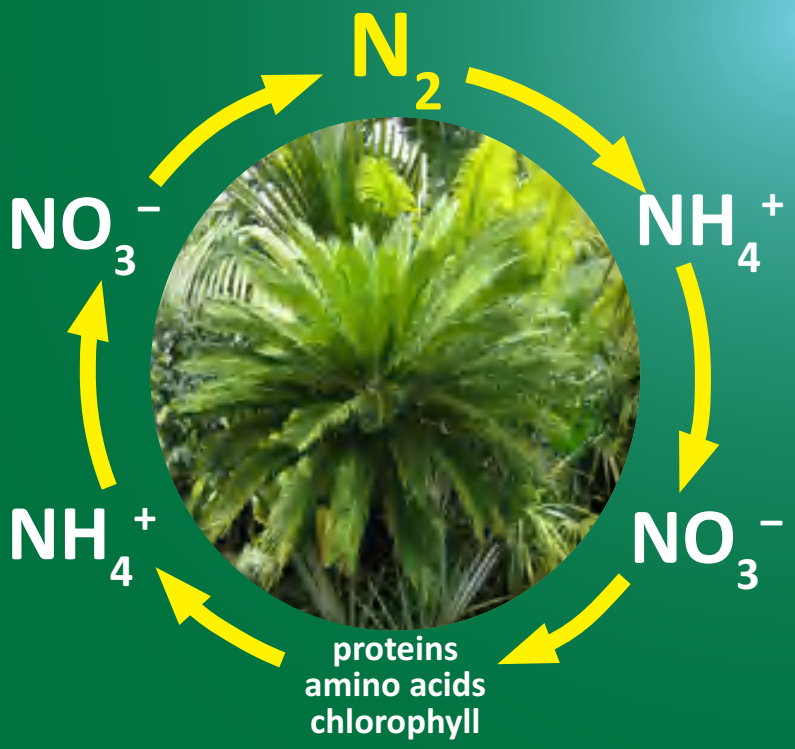
Balance the chemical equations.

15 Nitrogen cycle

7
N
NITROGEN

KEY TOPICS

1. Why is the amount of nitrogen in air almost constant?
2. Why is not N_2 directly assimilated by plants and animals?
3. What is the nitrogen cycle?
4. Does man affect the nitrogen cycle in nature?



KEY WORDS

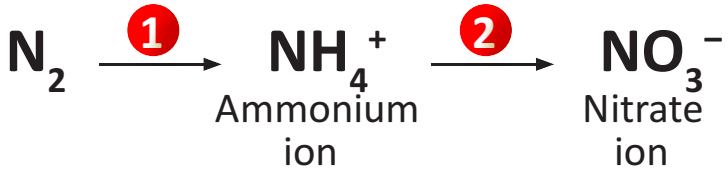
- Nitrogen cycle
- Fixation
- Nitrogen-fixing bacteria
- Nitrification
- Assimilation
- Ammonification
- Denitrification

NITROGEN is everywhere – 78 % of the dry air are nitrogen molecules N_2, all living organisms contain nitrogen as it is indispensable for the synthesis of proteins and nucleic acids, nitrogen compounds are found in both the lithosphere and the biosphere. As nitrogen or nitrogen compounds do not accumulate anywhere, it is obvious that in nature these substances are subjected to many chemical and biological transformations assuring the „balance“ of nitrogen in all its „forms“ on Earth. All these complex processes form the CYCLE OF NITROGEN IN NATURE. One can imagine „containers“ of nitrogen in various forms exchanging it with the help of biochemical processes.

The exchange of nitrogen between the atmosphere, the biosphere and the geosphere (the solid part of Earth and the mantle) is called NITROGEN CYCLE.

It is one of the major biochemical cycles in nature.

Nitrogen from air cannot be used by living organisms because the triple N≡N bond in the nitrogen molecule N_2 is very strong. So it must be transformed into other „usable“ forms. In these transformations the main role is attributed to different bacteria in the soil. They convert the atmospheric nitrogen absorbed by the soil into ammonium NH_4^+ ions and then into nitrate ions which can be assimilated by plants and animals:



These first two stages of the nitrogen cycle are known as *fixation* and *nitrification*:

1. *fixation* – nitrogen is transformed into ammonium ions NH_4^+. Bacteria making this conversion possible are known as *nitrogen-fixing bacteria*.
2. *nitrification* – ammonium ions NH_4^+ are changed into nitrate ions NO_3^-.

These processes undergo only in the presence of oxygen (aerobic processes). So they take place in oxygen-rich area as flowing water and the surface layers of soils and sediments.

Additionally, during lightning discharges in the atmosphere is formed nitrogen oxide NO. It reaches the soil with the acid rains as nitric acid HNO_3. It reacts with some carbonates in the soil and transforms into nitrates too. Forest fires and hot lava flows are natural processes going on at elevated temperatures The triple N≡N bond breaks down liberating single nitrogen atoms N which are very reactive. Thus molecular nitrogen N_2 converts into usable forms absorbed by the soil.

Man's activity is also a source of fixed nitrogen in soil – burning of fossil fuels, use of synthetic fertilizers, legumes crops and green manures are important sources of nitrates in soils. During the last sixty years the amount of nitrates in the soil resulting of the human activities has almost doubled.

Plants and animals get the nitrates from soil. This is the third stage of the nitrogen cycle:

3. *assimilation* – plants absorb (in their roots) nitrates from soil. Nitrates are transformed into different organic compounds indispensable to the plants growth (protein, amino acids, chlorophyll). Animals eat plants.

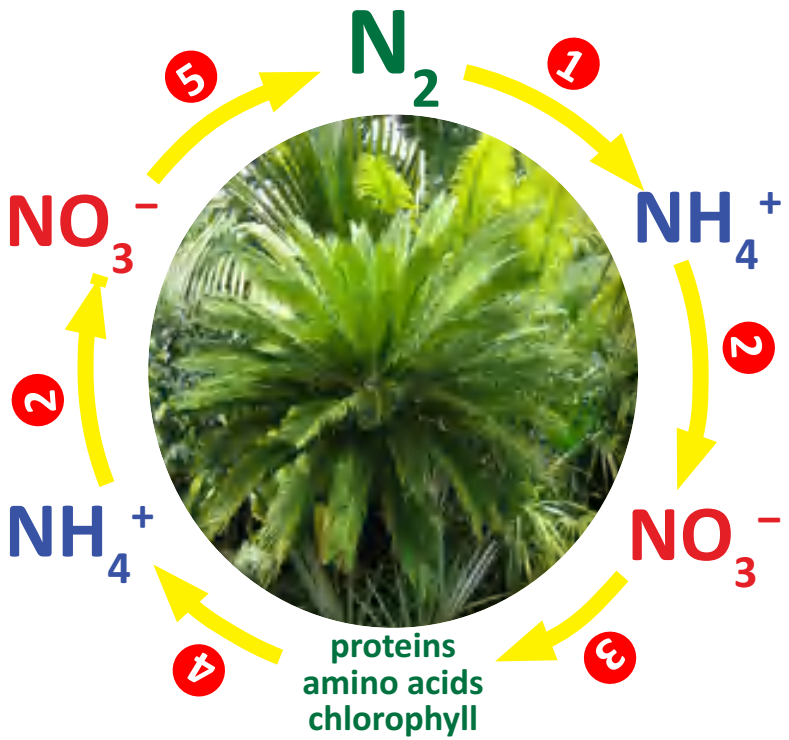
Some plants receive nitrogen from air by means of an unique types of bacteria converting the atmospheric nitrogen into forms assimilated by the plants.

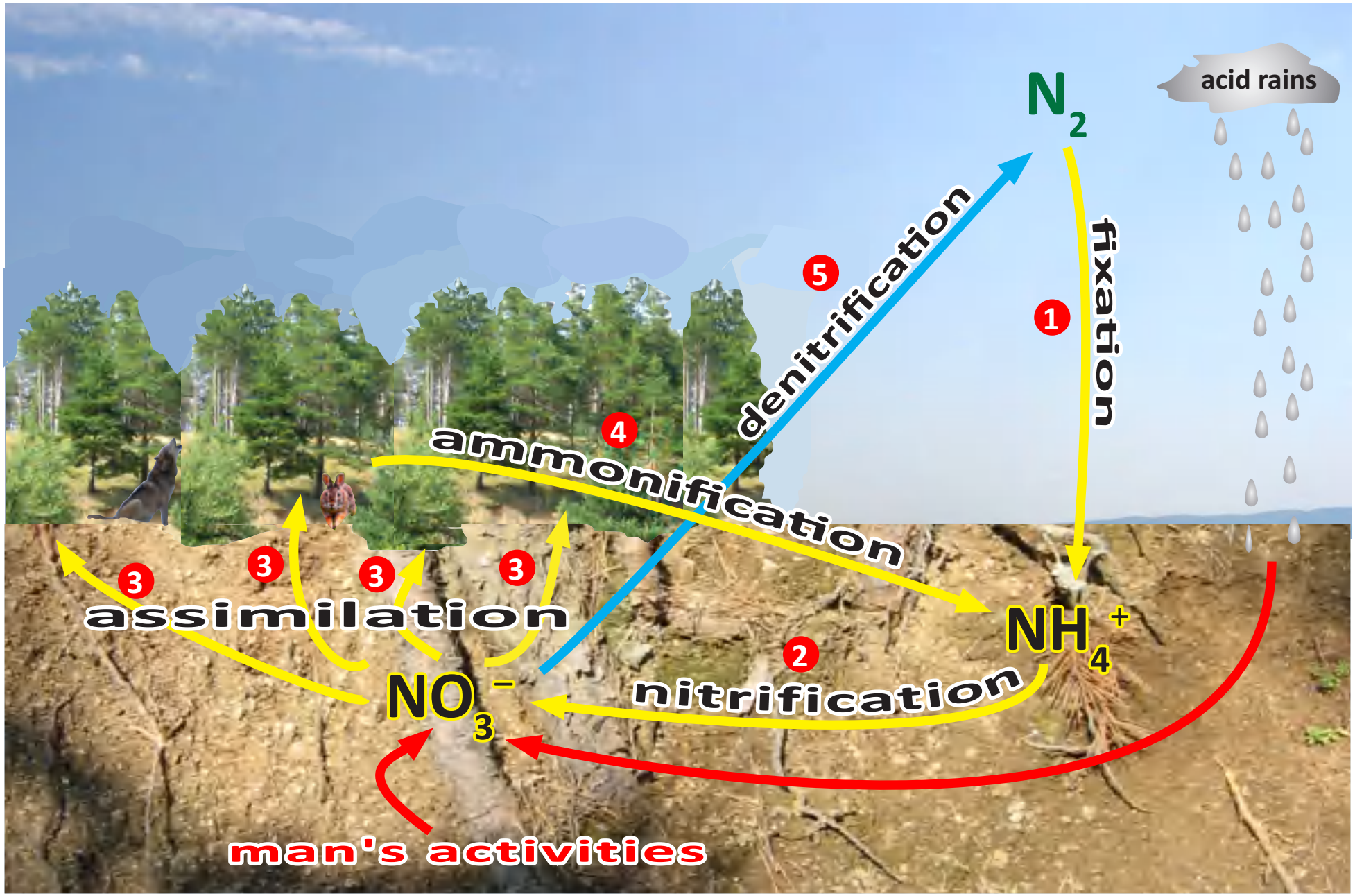
The next processes of the nitrogen cycle are the *ammonification* and the *denitrification*:

4. *ammonification* – when animals or plants die they decompose (decay) and specific bacteria transform the nitrogen compounds back into ammonium ions NH_4^+. They can be used again in the process of nitrification.

5. *denitrification* – the unused nitrogen in the soil returns back into the air. This process also undergoes with the help of specific denetrificating bacteria.

Denetrification is an anaerobic process returning back nitrogen in the air. Thus the cycle of nitrogen closes:





HOW IS NITROGEN CYCLING IN NATURE?

CAN YOU ANSWER THESE QUESTIONS ?

1. What is the nitrogen cycle in nature?
2. Why is nitrogen cycle vital for all living organisms on Earth?
3. Why is molecular nitrogen unusable by plants and animals?
4. What are the five main stages of the nitrogen cycle?
5. What is the role of bacteria for the transformations of nitrogen in nature?
6. Why do lightning discharge, volcanos activity and acid rains affect the cycle of nitrogen?
7. Does man's activity affect the cycling of nitrogen?

16 Importance of nonmetals and their compounds

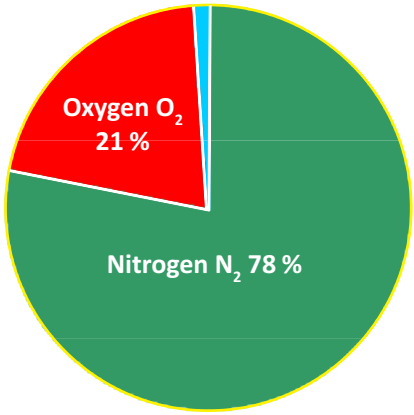
KEY TOPICS

1. Why are nonmetallic elements so important for life?
2. What is the physiological role of nonmetals?
3. What are nonmetals used for?
4. Why are ammonia, sulfuric acid and nitric acid so important compounds?



NONMETALS are much less than metals but they are of great importance for the living nature as well as for the chemical and other industries.

The Earth atmosphere (the air) is composed of nonmetals. Dry air is composed mainly of nitrogen **N_2** (78 %) and oxygen O_2 (21 %). The other constituents – carbon dioxide **CO_2**, inert gases (mainly argon **Ar**), hydrogen **H_2** and others occupy only 1 % of the volume of the dry air.



COMPOSITION OF DRY AIR

Hydrogen **H** and oxygen **O** form the most abundant chemical compound on Earth – the water H_2O. It is one of the simplest chemical compounds but it exhibits a lot of exceptional properties which determines the physical, chemical and biological nature of life. Besides carbon **C** which is in the origin of life, also hydrogen **H**, oxygen **O**, nitrogen **N**, phosphorus **P**, sulfur **S** are the most important elements building plants, animal tissues, our bodies. These elements are often summarized by the combination **CHONPS**.

IN BRIEF, LIFE IS BASED ON NONMETALLIC ELEMENTS.

PHYSIOLOGICAL ROLE OF NONMETALS AND THEIR COMPOUNDS

Oxygen O is the chemical element of greatest importance for life on the Earth. In nature **oxygen O_2** is produced by the green plants in the process of photosynthesis. For man it is absolutely indispensable to maintain life. In contrary **ozone O_3** is toxic, causes headache and other health problems.

Nitrogen N and **Phosphorus P** are element of great importance for the living organisms. Nitrogen is a part of any living organism as it is a key element of amino acids – the building blocks of proteins. Both nitrogen and phosphorus are present in some biologically important molecules – **DNA** (**D**eoxy-ribo**N**ucleic *A*cid), **RNA** (**R**ibo**N**ucleic **A**cid), **ATP** (**A**denosine **T**ri**P**hosphate). Nitrogen is also important for plant grows.

The gas N_2 itself at STP is not chemically active and has no effect on the living organisms. At high pressure, however (as it is the case with the divers at great depths in the sea), the concentration of the dissolved in tissues nitrogen increases and this causes the so called „nitrogen narcosis“ – the result is a loss of coordination of movements and even a loss of conscience. To prevent this harmful effect a helium-oxygen mixture instead of air is used.

Sulfur S is nontoxic and it is essential to life as it is indispensable to make some proteins.

Generally the compounds of sulfur are not toxic but **H_2S** and **SO_2** are poisonous gases and should not be inhaled. Hydrogen sulfide at low concentration smells like „rotten eggs“ but after a long exposure or at high concentrations the ability to smell the gas is lost. Hydrogen sulfide is an extremely hazard-ous compound and cause death.

Sulfur dioxide SO_2 destroy the lower organism and for this reason is used in the canning industry.

Hydrogen sulfide and sulfur oxides as well as nitrogen oxides in air can cause acid rains.

USES OF NONMETALS AND THEIR COMPOUNDS

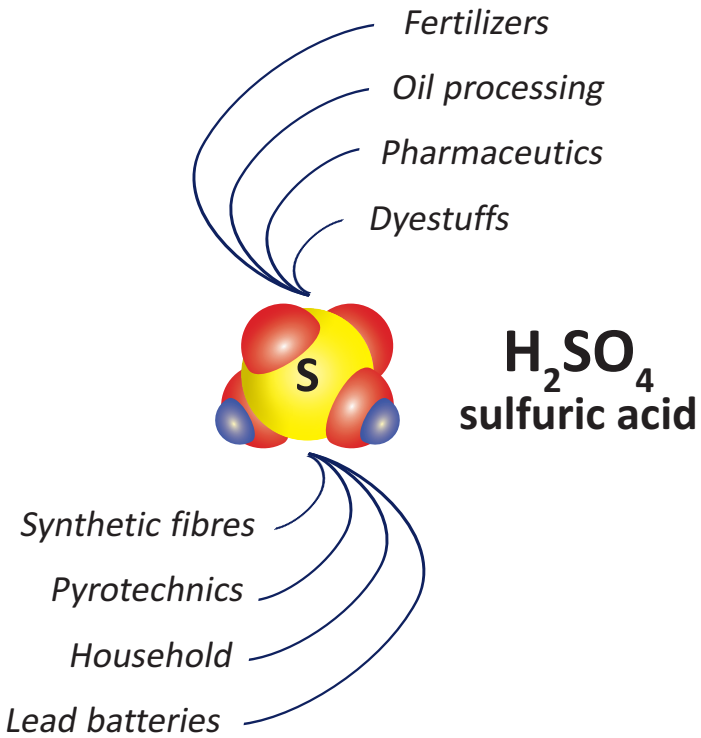
Nonmetals and their compounds are widely used in our everyday life as well as in many industrial processes.

Oxygen O_2 oxidizes fuels (burning), it is indispensable for the chemical industry and the metallurgy, the agriculture, the pharmaceutical industry and the medicine, the aerospace technologies, the manufacture of glass, etc. In short oxygen is practically used everywhere in man's activities.

Sulfur S is an important for the chemical industry nonmetal – in the world each year are produced millions of tonnes of sulfur. It is used for the vulcanization of rubber, for the production of safety matches and gunpowder, spacial paints and dyes. SO_2 is a bleaching agent and is used in the production of cellulose and paper, also in the production of wine as well as in the food and canning industry as a preservative.

But most sulfur is used in the production of sulfuric acid H_2SO_4 – maybe the most important chemical product in the developed countries. Yearly in the world are produced hundred of millions of tonnes of sulfuric acid. Here are some of the more important uses of H_2SO_4.

Sulfates are also widely used compounds. Well known are *gypsum* $CaSO_4$(calcium sulfate) and *blue vitriol* $CuSO_4$ (copper sulfate). Yearly more than 100 millions of tonnes of gypsum are used in the production of cement and plaster. Blue vitriol is used in agriculture. A mixture of $CuSO_4$ and slaked lime $Ca(OH)_2$ is known as Bordeau mixture (solution) and is used as an insecticide for the protection of plants.



SOME USES OF SULFURIC ACID

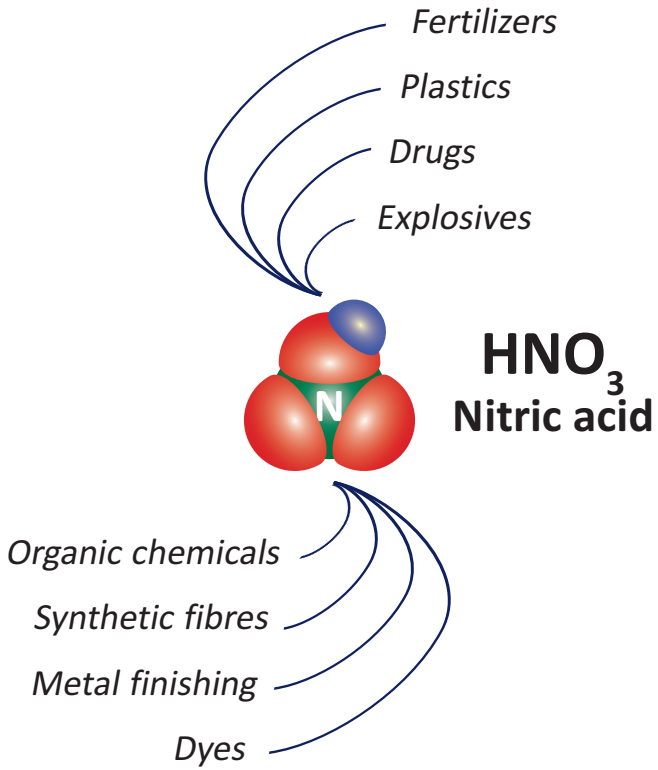
Nitrogen N_2 is mostly used in the production of ammonia NH_3, nitric acid HNO_3, nitrogen fertilizers, drugs, explosives, etc.

The triple nonpolar covalent bond **N ≡ N** in the nitrogen molecule N_2 is so strong that it is almost nonreactive. That explains many of its uses. Nitrogen gas N_2 is used to preserve foods (as the N_2 atmosphere is nonreactive). This is also indispensable for the electronic industry. Nitrogen gas is also used in metallurgy to make steel easier to work (the process is known as annealing of steel). Nitrogen gas can be liquefied at a very low temperature 77 K (–196 °C). Liquid N_2 is a refrigerant and is indispensable to store cells for medical research or for reproduction. Foods are also quickly frozen to preserve their nutritiousness.

The use of N_2 in the industry more often requires its transformation into **ammonia NH_3**. it is used in the production of nitric acid, mineral fertilizers, dyes, plastics, drugs, etc. The annual production of ammonia on a world scale is in the order of hundreds of millions of tonnes. In the everyday life ammonia is used for bleaching of nylon, silk and wool, for washing of coloured fabrics, for stain removal, in medicine, etc.

Nitric acid HNO_3 is one of the most important compounds of nitrogen. It is also one of the most important products in the chemical industry – its annual production exceeds 50 millions of tonnes. It is used in the production of mineral fertilizers ($NaNO_3$, KNO_3, NH_4NO_3) dyes, explosives, plastics, drugs, etc. It is also applied in the processes of cleaning, etching and engraving of metallic surfaces.

Saltpetres (nitrates of 1A and 2A group elements and of ammonia) are used as fertilizers. $NaNO_3$ and KNO_3 are preservatives. KNO_3 is highly hygroscopic and is used in explosives. The gunpowder is a mixture of KNO_3, coal and sulfur.



SOME USES OF NITRIC ACID

Phosphorus P is a component of all matches as it ignites easily. First was used wight phosphorus but today safety matches contain red phosphorus as it is less volatile and less poisonous. Besides this very well known application, phosphorus and its compounds have other very important uses:

- some phosphorous compounds „stop fire“. They are additives used for the production of synthetic fire-resistant materials;
- some phosphorus organic compounds are good lubricants;
- phosphates (salt of phosphoric acid H_3PO_4) coating protect some metals as iron, zinc, manganese;
- phosphoric acid is used to clean metal surfaces;
- soluble phosphates are used to purify water, especially to remove unwanted metal salts;
- as phosphorus is a very important element for plants, some phosphates are widely used a fertilizers;
- phosphorus compounds are used as pesticides.

Phosphorus is present in our everyday life too. For example special glasses and fine dishes are made with the help of phosphorus, the well known baking powder contain phosphorus and many others.



Safety matches
(Phosphorus ignites readlly)



Fine porcelain

15 (5A)
15
P
3
PHOSPHORUS
30,97

$NaHCO_3$ + NaH_2PO_4
baking powder



Fireworks

PHOSPHORUS
IN EVERYDAY LIFE

CAN YOU ANSWER THESE QUESTIONS ?

1. Are nonmetals numerous?
2. Why are nonmetallic elements so important for life?
3. Why is liquid nitrogen used to preserve foods, plants and human organs?
4. What is „nitrogen narcosis“?
5. Why are important documents kept under nitrogen atmosphere?
6. Are H_2S and SO_2 harmful gases?
7. Why are every year millions of tonnes of $NH_{3,}$, H_2SO_4 and HNO_3 produced in the world?
8. What sulphates do you know and what are they used for?
9. Why is phosphorous used in matches and fireworks?
10. What uses of phosphorous compounds do you know?
11. Do you know what is the most abundant compound on Earth made of two nonmetallic elements?
12. What substances around you are built up mainly of nonmetallic elements?

PROJECTS

1. THE MOST ABUNDANT CHEMICAL COMPOUND

Find out what is the most abundant chemical compound on Earth. Learn about its structure and properties. What it is used for in the everyday life? Can you imagine what will happens if it suddenly disappears on Earth?

2. OXYGEN AND LIFE

Why is oxygen indispensable for life? Why does the quality of life depend on the quality of air?

3. MINERAL FERTILIZERS AND FERTILIZING

Prepare and organize in class a discussion regarding the advantages and the disadvantages of mineral fertilizers and fertilizing.

4. NONMETALS IN THE NEW MATERIALS

Learn about some new materials with surprising properties. What nonmetallic elements do they contain? What is their role?

You can find helpful information on www.cas.org – look at CAS REGISTRY^{SM} (the gold standard for chemical substance information).