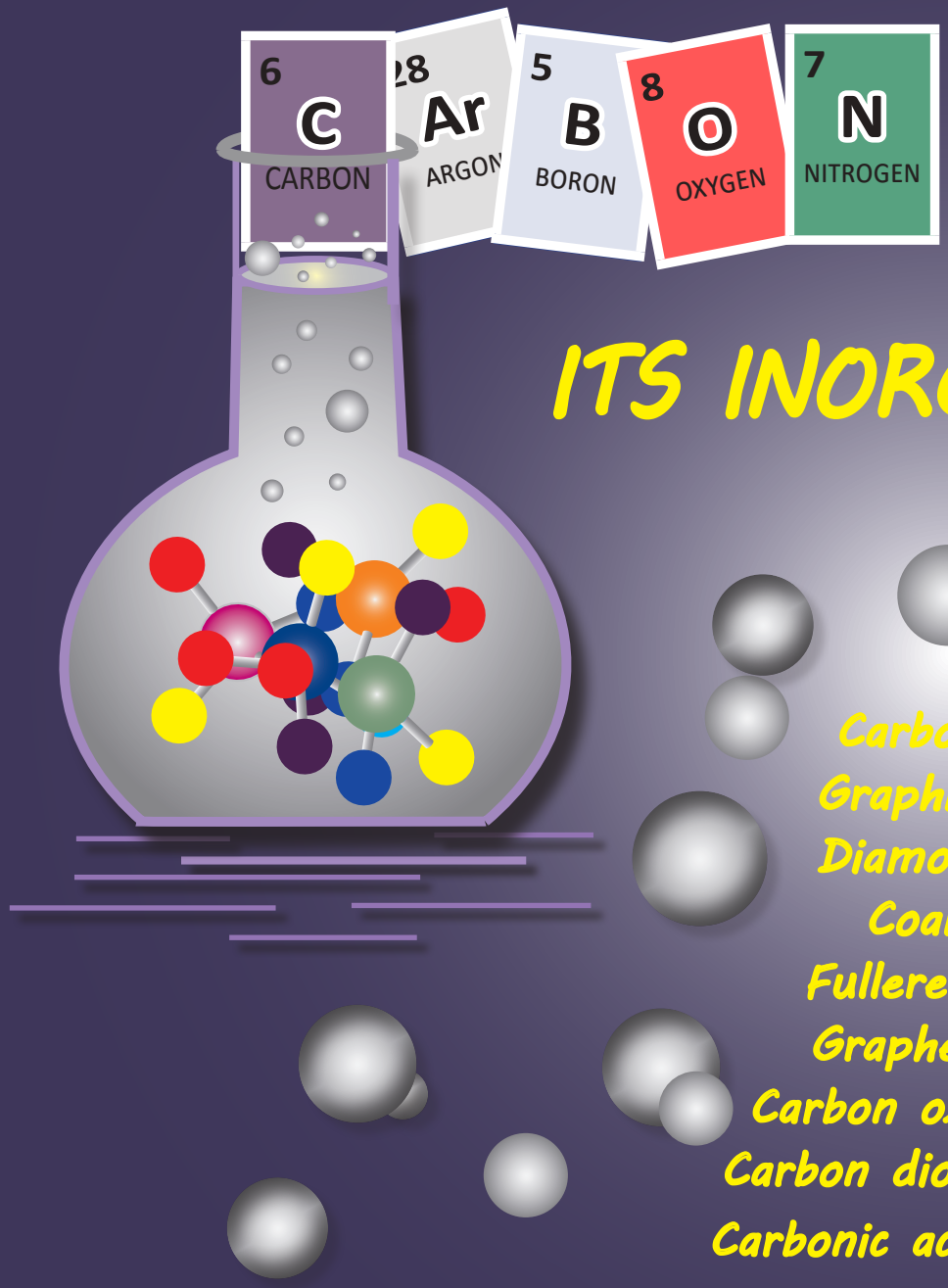


and ITS INORGANIC COMPOUNDS

Carbon C
Graphite C
Diamond C
Coal C
Fullerenes C
Graphene C
Carbon oxide CO
Carbon dioxide CO_2
Carbonic acid H_2CO_3



19 CARBON 3

20 CARBON OXIDES.
Carbon oxide CO. Carbon dioxide CO_2 14

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PROJECTS 27

Click on a topic to jump to the page

19 Carbon

6
C
CARBON

KEY TOPICS

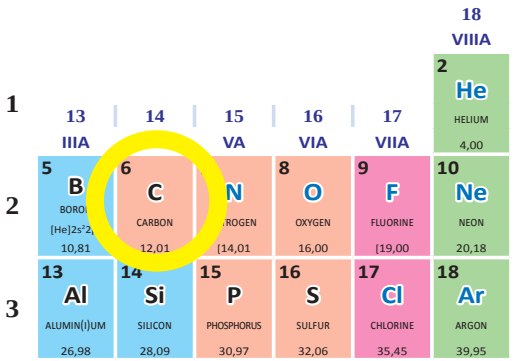
1. Why do we pay so special attention to carbon?
2. Why do diamond and graphite have so different physical properties?
3. Are there man-made allotropes of carbon?
4. Is carbon a reactive element?



KEY WORDS

- Diamond
- Graphite
- Fullerenes
- Graphene
- Carbon oxide
- Carbon monoxide
- Carbonic acid
- Carbonates

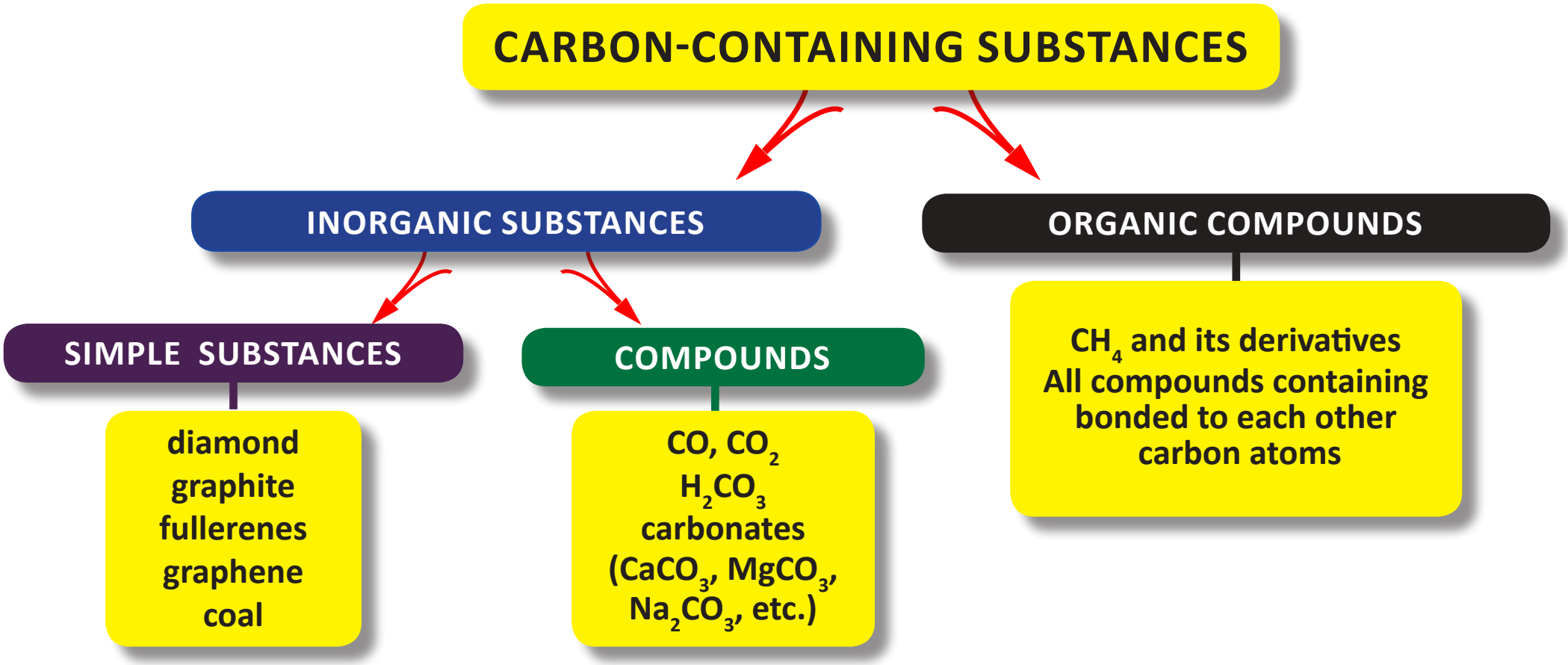
CARBON C is the sixth element in the Periodic table. It is a period 2 and 14 (IVA) group element. It got its name from the Latin word „carbo“ which means coal or charcoal. About 99 % of carbon in the universe is carbon-12 (with 6 protons and 6 neutrons in its nuclei). About 1 % is carbon-13 (with 6 protons and 7 neutrons in its nuclei). Only a small amount (less than 1 %) of the naturally occurring carbon is the radioactive isotope with 6 protons and 8 neutrons in the nuclei (carbon-14) but it is very important as it is used to date organic matter.



Carbon makes up 18 % of the human body by mass. It exists as several simple substances (allotropes of carbon). The most important are diamond, graphite, fullerenes. Graphene (a new man-made material with famous properties) is also made of carbon atoms. Carbon builds the molecules of the main compounds of petroleum and natural gas and is also found in the Earth's crust as the mineral calcite $CaCO_3$ (the main component of limestone, marble) and others minerals ($MgCO_3$ magnesite, $SrCO_3$ strontianite, $BaCO_3$ whiterite, etc.). The main component of coal, charcoal and soot is also carbon. They are amorphous substances. In the atmosphere carbon is present mainly as carbon dioxide CO_2.

The oxides of carbon (CO and CO_2) , the carbonic acid H_2CO_3 and its salts and some other carbon-containing compounds are ***inorganic compounds***.

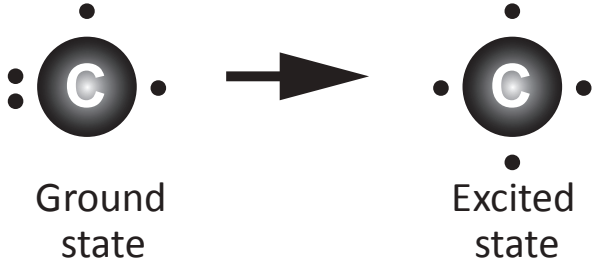
Carbon atoms have the famous property to bond to one another thus forming long chains. The simplest hydrogen compound of carbon CH_4 (methane), its derivatives and all compounds in whose molecules two or more carbon atoms are bonded in chains, are called ***organic compounds***. They are the building blocks of all living organisms (this makes carbon so special for life on the Earth), of petroleum and natural gas. Carbon makes more compounds than all other elements. Nearly 10 millions of different carbon-containig compounds are known. The structure and the properties of organic compounds are unique (you will become familiar with that matter in the next chapters).


CARBON-CONTAINING SUBSTANCES
INORGANIC SUBSTANCES
ORGANIC COMPOUNDS
SIMPLE SUBSTANCES
COMPOUNDS
diamond
graphite
fullerenes
graphene
coal
CO, CO2
H2CO3
carbonates
(CaCO3, MgCO3,
Na2CO3, etc.)
CH4 and its derivatives
All compounds containing
bonded to each other
carbon atoms

SIMPLE SUBSTANCES OF CARBON – STRUCTURE and PHYSICAL PROPERTIES

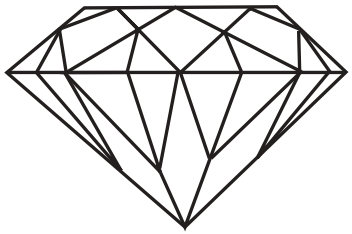
All simple substances of carbon are solid at standard conditions. But carbon atoms build different 3D (or 2D) patterns in the different simple substances and consequently the physical properties of these allotropes are also quite different.

DIAMOND has an atomic crystal lattice in which each carbon atom forms four equal in strength and length covalent bonds with four neighbour carbon atoms. It is called a „diamond lattice“. This is a giant molecule formed of strictly arranged in the space carbon atoms. Each carbon atom has 4 valence electrons. Normally (in ground state) two of these valence electrons are paired and two – unpaired. In excited state the electron pair disrupts and all 4 valence electrons are used to form chemical bonds with the 4 neighbour carbon atoms thus forming a very stable tetrahedral structure.

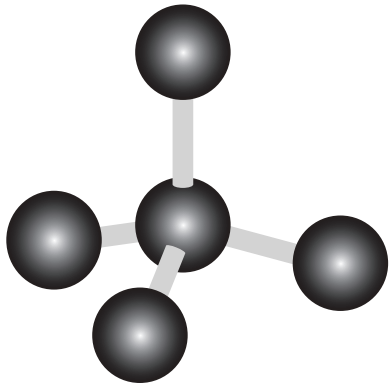


Ground state

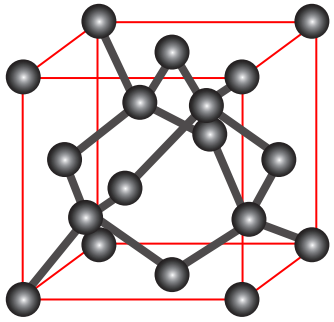
Excited state



DIAMOND



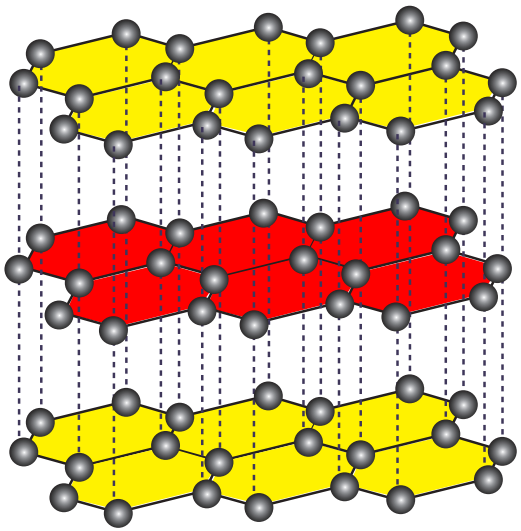
BONDING OF CARBON ATOMS IN DIAMOND



Diamond is one of the hardest substances. It is a colourless, transparent, intensively reflecting the light substance with a very high melting point. It does not conduct electricity.

Diamonds (brilliants) are used to make jewellery as they are very beautiful (they are lustrous as they sparkle and reflect light). As diamond is very hard it is used to make cutting and drilling tools, stones for watches , measuring devices, etc.

GRAPHITE is a greyish-black, non-transparent substance with a metallic lustre. It is soft and oily in touch. Similarly to diamond it is a crystalline substance made up of covalently bonded carbon atoms. But unlike the lattice of diamond the atomic lattice of graphite is built up of many layers of carbon atoms – each carbon atom forms three equal in length and strength covalent bonds with three other carbon atoms forming hexagons situated in a plane. The fourth covalent bond is formed between two carbon atoms of neighbour parallel planes. It is more than twice as long as the other three bonds and hence it is not so strong. Consequently, the electrons of the two bonding atoms on neighbour planes are „delocalized" – they move freely along the atomic plane thus assuring the electrical conductivity of graphite (unlike typical nonmetals).



BONDING OF CARBON ATOMS IN GRAPHITE

The graphite crystal may be regarded as built up of giant planar molecules held together as in a wad. Graphite is a soft material as the neighbour layers slip easy relatively to each other. Its melting point is high. Graphite is black as moving electrons absorb all lengths of the visible light.

Graphite is used in the manufacture of pencils (it splits and leaves traces on paper), lubricants, heat insulating materials and black paints. Graphite electrodes are used in electrochemistry and electrometallurgy also in nuclear reactors to retard neutrons.

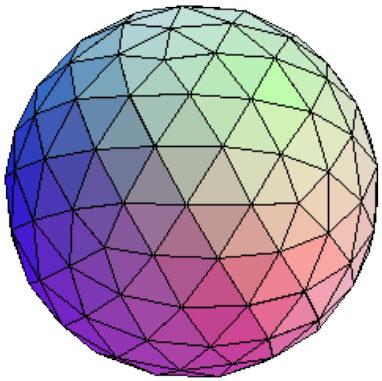
At temperatures above 1000 ^{O}C and in the absence of air diamond slowly transforms into graphite:

$$\text{DIAMOND} \xrightarrow[\text{absence of air}]{\text{above 1 000 }^{o}\text{C,}} \text{GRAPHITE}$$

The reverse reaction (the transformation of graphite into artificial diamonds) is also possible but only under specific conditions.

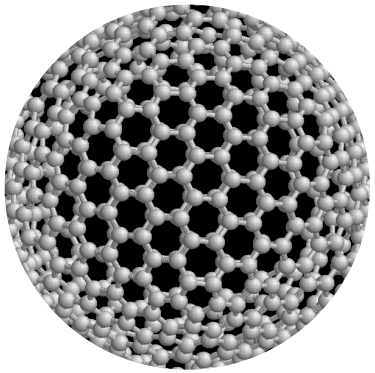
Other simple substances of carbon are *coke*, *soot*, *coal* and *charcoal*. They are amorphous substances. According to the World Coal Association about 30 % of the energy on a world scale is provided by coal (it is the second source of primary energy after oil). Coke is used in metallurgy for the production of metals from their ores and in the manufacturing of electrodes. Soot is a product of incomplete combustion and is applied in the production of paints and gun powder. Charcoal is obtained from wood or animal tissues, bones, etc. Activated carbon (usually obtained from charcoal) has a great adsorption ability and is used in medicine, to treat poisonings, in gas-protective masks, for the purification of solutions, etc.

FULLERENES and GRAPHENE are more recently discovered allotropes of carbon. Fullerenes are found in the universe but for the purposes of nanotechnology they are synthesized by man. Graphene in not found in nature. It is a man-made material.



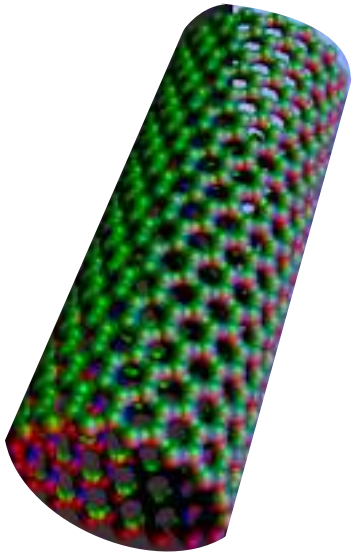
GEODESIC SPHERE

FULLERENES are giant molecules in the form of cage-like hollow spheres, ellipsoids or tubes composed of many carbon atoms. Carbon atoms are linked by covalent bonds forming most often hexagonal, but also pentagonal or sometimes heptagonal rings. Fullerenes are named after the engineer, architect and futurist Richard Buckminster Fuller as his constructions (geodesic domes) resemble to geodesic spheres whose structure is similar to that of spherical fullerenes (named buckyballs).



FULLERENE (BUCKYBALL)

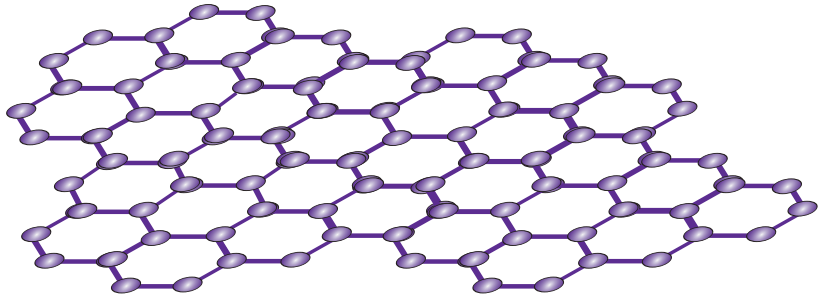
The first fullerene was discovered in 1985 by Robert F. Curl, Jr., Sir Harold W. Kroto and Richard E. Smally. They were awarded the Nobel Prize in chemistry in 1996. This fullerene was built up of 60 carbon atoms (C_{60}) forming a hollow sphere with 12 pentagonal and 20 hexagonal faces. Fullerenes may be regarded as composed of a sheet of linked carbon atoms rings which takes the form of a sphere (like a soccer ball), a tube, an ellipsoid. They are key materials for nanotechnology operating at the atomic level as they exhibit surprising mechanical and electronic properties (especially the nanotubes). They are used in the production of pharmaceutical and other new products, lubricants, semi-conductor, catalysts*.



FULLERENE (BUCKYTUBE)

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

GRAPHENE is a man-made nanomaterial. It was isolated in 2004 by Andre Geim and Konstantin Novoselov (they were awarded the Nobel Prize in physics in 2010). Its structure is two-dimensional – a layer of 6-carbon atoms ring forming a crystal lattice (a honeycomb hexagonal arrangement). In a way this is one graphite layer. This simple substance displays extraordinary properties and is considered as one of the materials of future.



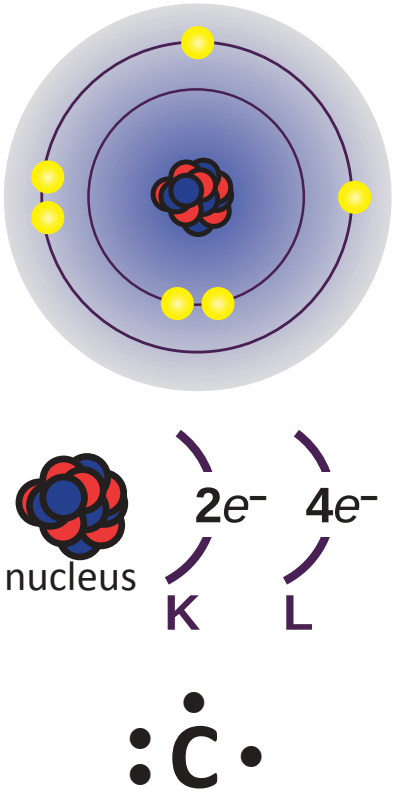
GRAPHENE

Graphene is just one atom tick but it is among the strongest materials (200 times stronger than steel) being in the same time very flexible. It is ultra-light, transparent, superb conductor and a perfect barrier. These amazing properties determine its future applications. Scientists expect to use graphene to produce tiny light bulbs, superconductors (graphene does not resist to electron flows), new audio devices (they could be incorporated into ultrathin touchscreens, ultrathin body armour (flexible but strong as diamond), membrane filtering the salt out of seawater, new batteries recharging superquickly, running shoes more resistant to wear and tear. It is a promising material for medicine (can help to detect cancer cells), for the space industry and many other surprising uses.

CHEMICAL PROPERTIES OF CARBON

Generally under standard conditions the simple substances of carbon have a low reactivity (the carbon atoms in the atomic lattices are held together by strong covalent bonds). Carbon reacts only at high temperatures. It is a typical nonmetal.

The carbon atom has 6 electrons in its electron shell – an electron pair in the nearest to the nucleus K shell and 4 electrons in the outermost (valence) L shell. Normally (in ground state) two of the four valence electrons are paired and two – unpaired. If carbon atoms use only their lone valence electrons to bond to other atoms they are divalent. In excited state (see p. 6) carbon atoms use all four valence electrons to form chemical bonds with other atoms and consequently they are tetravalent. Typical are the reactions with hydrogen and oxygen.



LEWIS-DOT FORMULA

THE CARBON ATOM (Z = 6)

REACTION WITH OXYGEN

Carbon burns and forms carbon monoxide (or simply carbon oxide) CO if there is not enough oxygen to oxidize it fully. When excess of oxygen is used the product is carbon dioxide CO_2. In both reactions heat is released:

$$2C + O_2 \xrightarrow{t^o} \underset{\text{Carbon monoxide}}{2CO} + heat \qquad \text{(carbon is divalent)}$$

$$C + O_2 \xrightarrow{t^o} \underset{\text{Carbon dioxide}}{CO_2} + heat \qquad \text{(carbon is tetravalent)}$$

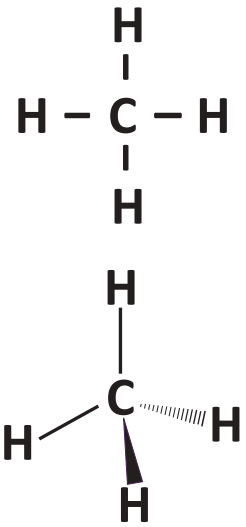
REACTION WITH HYDROGEN

With hydrogen carbon forms millions of compounds, named hydrocarbons. Hydrocarbons and their derivatives are the subject of the organic chemistry (you will learn more about them in the next chapters). The simplest hydrocarbon is methane CH_4. It is the product of the reaction of carbon with hydrogen that takes place at a high temperature:

$$C_{(solid)} + 2H_{2(gas)} \xrightarrow{t^o} CH_{4(gas)}$$

As the temperature rises the reverse reaction takes place – methane decomposes.

In the methane molecule CH_4 carbon is teravalent. The four carbon-hydrogen bonds are equal in strength and length and hydrogen atoms are symmetrically distributed around the central carbon atom – the molecule is nonpolar.



METHANE CH_4

CAN YOU ANSWER THESE QUESTIONS ?

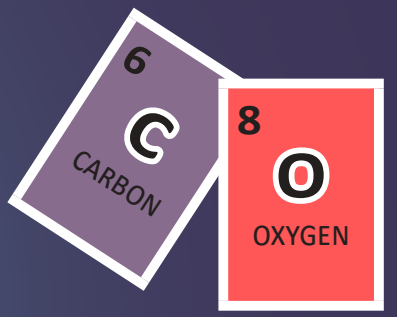
1. Why are all allotropes of carbon solid at STP?
2. Which of the simple substances of carbon are amorphous and which – crystalline?
3. Why does graphite conduct electricity, while diamond is an insulator?
4. Why is carbon divalent in some of its compounds, while in others it is tetravalent?
5. What are fullerenes?
6. Why is graphene considered as an innovative material?
7. What oxides of carbon do you know?
8. What is the simplest compound composed of carbon and hydrogen?

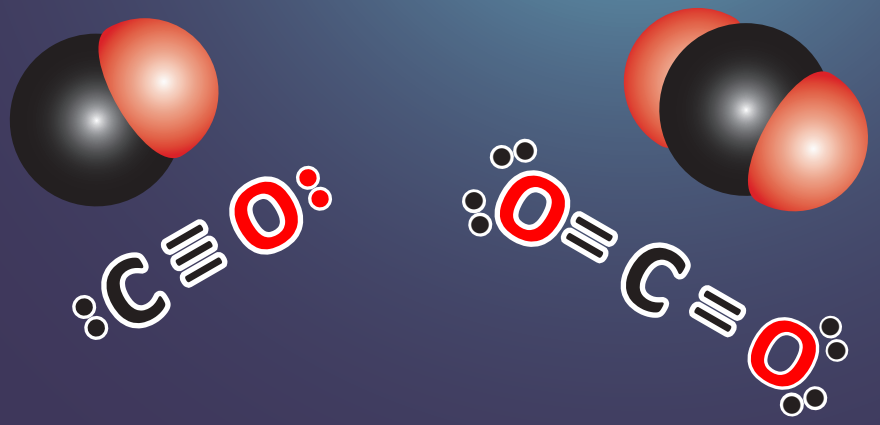
20 Carbon oxides.

Carbon monoxide CO. Carbon dioxide CO_2

KEY TOPICS

1. Why does carbon form two oxides?
2. Why is CO a poison?
3. What is a neutral oxide?
4. Does CO_2 burn? Why?
5. WHY IS CO_2 USED AS A COOLING AGENT?





KEY WORDS

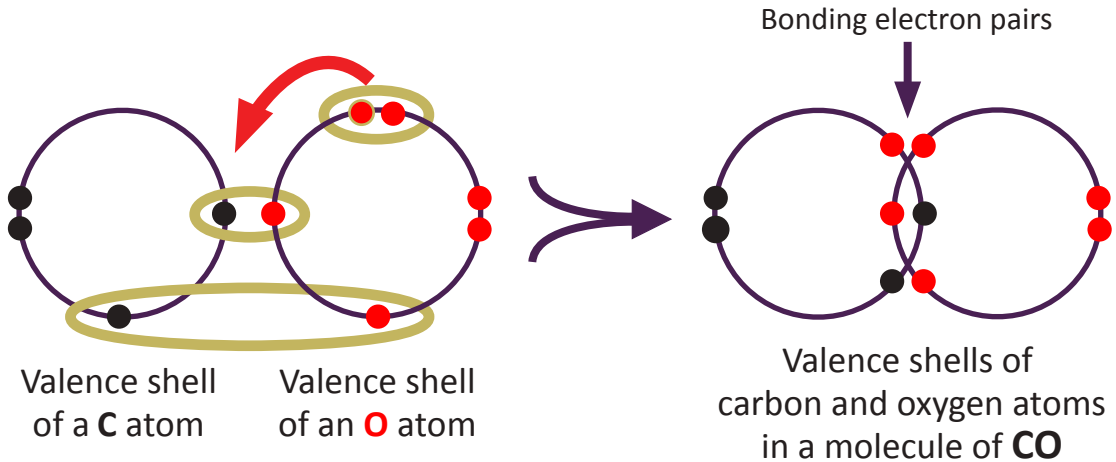
- Carbon monoxide
- Neutral oxide
- Carbon dioxide
- Dry ice
- Carbonic acid
- Carbonates

Carbon forms two oxides – carbon monoxide CO and carbon dioxide CO_2.

CARBON MONOXIDE CO



In carbon monoxide carbon is divalent as it uses its two lone valence electrons to form two bonds with oxygen. But the carbon-oxygen bond in the CO molecule is a triple bond (see the chapter Structure of matter, p. 28). This seems a little bit confusing but the third bond is formed by one of the valence electron pairs of oxygen. The molecule is polar.



FORMING OF THE CO MOLECULE

Under standard conditions CO is a colourless, odourless gas, lighter than air. It is slightly soluble in water but does not react with it and has no corresponding acid. It does not react either with bases or with acids. Such oxides are called neutral oxides. (Besides CO, N_2O and NO are also neutral oxides.)



CARBON–OXYGEN BONDING IN THE MOLECULE OF CARBON MONOXIDE CO.
LEWIS-DOT FORMULA

Carbon monoxide forms when the amount of oxygen is not enough to produce CO_2 (for example when operating with stoves or internal combustion engines in an enclosed space).

Natural sources of CO are volcanoes, forest fires, photochemical reactions (they are initiated by the absorption of light) in the troposphere (the lowest layer of the Earth's atmosphere). Carbon oxide is an essential component of the coal gas widely used in the past for lighting, cooking and heating.

!!! Carbon monoxide is a strong blood poison. When inhaled it combines with the hemoglobin and forms carboxyhemoglobin which is much more stable than the normally formed oxyhemoglobin and thus interferes the oxygen supply to the cells:

$$\textbf{oxyhemoglobin} + \textbf{CO} \rightarrow \textbf{carboxyhemoglobin} + \textbf{O}_2$$

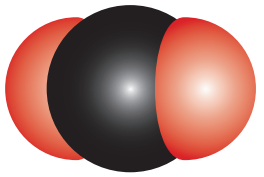
Even small amounts of CO (lower than 0,1 %) can cause asphyxiation and death. In case of CO intoxication the first aid should be the immediate supply of fresh air and artificial respiration procedures till medical intervention.

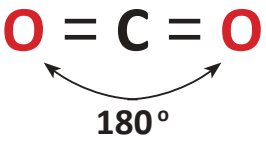
In oxygen atmosphere CO burns with a bluish flame releasing a considerable amount of heat (this explains one of its uses as a fuel):

$$\textbf{2CO} + \textbf{O}_2 \rightarrow \textbf{2CO}_2 + \textbf{heat}$$

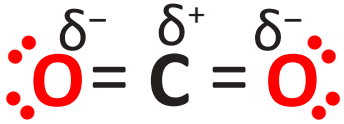
CARBON DIOXIDE CO_2

STRUCTURE AND PHYSICAL PROPERTIES





CARBON DIOXIDE
CO_2



POLAR BONDS
OF THE CARBON DIOXIDE
MOLECULE CO_2

In the molecule of CO_2 carbon is covalently double bonded to two oxygen atoms. Carbon is less electronegative and acquires a partial positive charge, while oxygen atoms are negatively charged. As a whole the CO_2 molecules are nonpolar because the two oxygen atoms are symmetrically distributed around the central carbon atom (the CO_2 molecule is linear). Their partial negative charges cancel the partial positive charge of the carbon atom.

At room temperature CO_2 is a colourless gas having a faint, sharp odour and sour taste. It is heavier than air and can be poured from one container to another or stored in open bottles. CO_2 is soluble in water – this property is used to prepare soft (carbonated) drinks. Carbon dioxide does not burn and is used in the fire extinguishers.

If compressed CO_2 liquefies. If liquid CO_2 suddenly expands to a pressure of 1 atm it freezes forming a snowlike solid called „dry ice“. It sublimates at about −80° C absorbing a large amount of heat. For this reason it is used as a cooling agent.

CO_2 is a minor component of the Earth’s atmosphere but it is a greenhouse gas − it absorbs some of the radiant energy thus causing the greenhouse effect (the warming of the Earth’s surface and the troposphere).

CO_2 is an end product of respiration. It has a suffocating action, therefore a frequent ventilation of rooms and supply of fresh air is necessary.

CHEMICAL PROPERTIES

Carbon dioxide is an *acidic oxide* − it reacts with water, basic oxides and hydroxides:

REACTION WITH WATER. When dissolved in H_2O carbon dioxide reacts with it. The product is carbonic acid H_2CO_3. It is unstable and easily decomposes into CO_2 and H_2O:

$$CO_2 + H_2O \rightleftarrows \underset{\text{Carbonic acid}}{H_2CO_3}$$

REACTION WITH BASIC OXIDES AND HYDROXIDES. As carbon dioxide is an acidic oxide it reacts with basic oxides and hydroxides forming salts named carbonates:

$$CO_2 + CaO \rightarrow \underset{\text{Calcium carbonate}}{CaCO_3}$$

$$CO_2 + 2NaOH \rightarrow \underset{\text{Disodium carbonate}}{Na_2CO_3} + H_2O$$

If CO_2 bubbles through a dilute solution of slaked lime $Ca(OH)_2$(pure limewater), the solution turns from clear to milky as $CaCO_3$ forms:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

THE REACTION WITH CLEAR LIMEWATER IS A TEST REACTION FOR CO_2.

Solid substances or solutions can be tested for carbonates with dilute hydrochloric acid HCl. CO_2 bubbles if CO_3^{2-} ions are present. For example lime reacts with HCl to produce calcium dichloride $CaCl_2$(soluble in water) and carbon dioxide:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2\uparrow$$

The liberation of the CO_2 gas is accompanied by a specific fizz (effervescence). This is a test reaction for carbonates. The liberation of CO_2 can be confirmed by bubbling the evolved gas through pure limewater.

CAN YOU ANSWER THESE QUESTIONS ?

1. Why does carbon form two different oxides?
2. Why is carbon monoxide a neutral oxide?
3. The CO molecule is polar while the CO_2 molecule is nonpolar. Why?
4. Why are soft drinks effervescent and with a slightly acidic taste?
5. CO_2 is rekeased when breathing. How can you prove it experimentally?
6. A person exhales when breathing about 50 g per hour CO_2. What is the volume of this gas at STP? (*Ans. 25,45 ℓ*)
7. What are carbonates?
8. How to test for CO_3^{2-} ions in a solution?

21 Carbon cycle

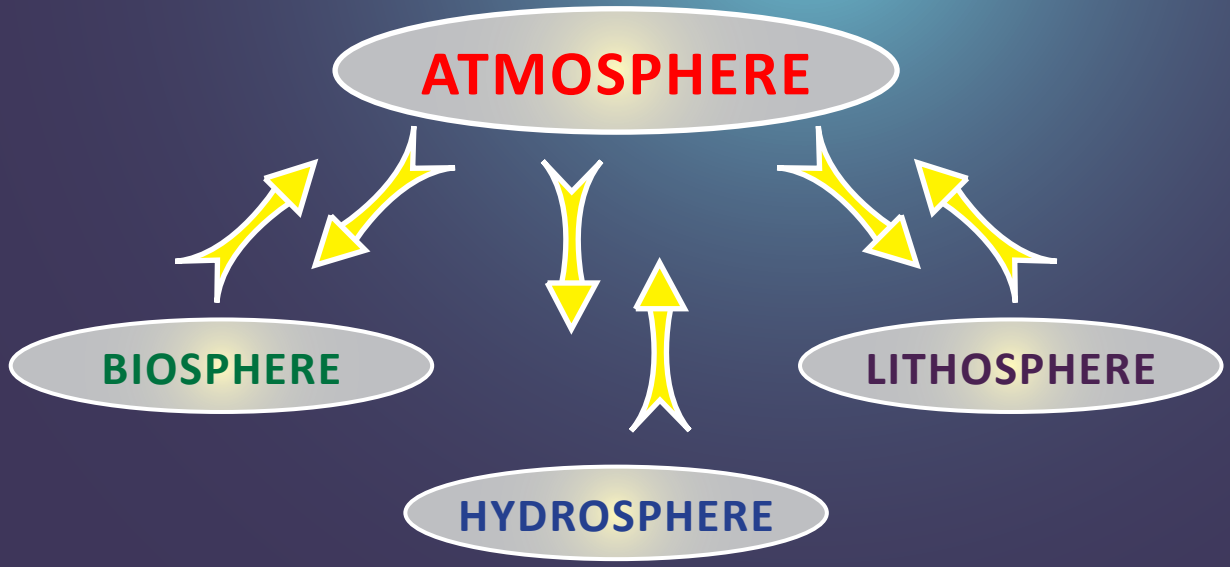
6
C
CARBON

KEY TOPICS

1. What is the carbon cycle in nature?
2. What are the major „containers“ of carbon in nature?
3. Why is carbon cycle important for the energy balance of the Earth?
4. How do human activities affect the carbon cycle?

KEY WORDS

- Carbon cycle
- Photosynthesis
- Global warming



Carbon is an element of life. All living organisms (plants, animals, man) contain carbon. This element is found also in the atmosphere, in natural waters, in rocks ($CaCO_3$, $MgCO_3$, etc.). All these „containers“ of carbon exchange it in different forms in a way to maintain a constant level of carbon-containing compounds. These complex processes assure the cycling of carbon in nature:

The exchange of carbon between the atmosphere, the biosphere, the hydrosphere and the lithosphere is called CARBON CYCLE.
It is one of the major biochemical cycles in nature.

Between 1 000 to 100 000 million tonnes of carbon move through the carbon cycle every year.

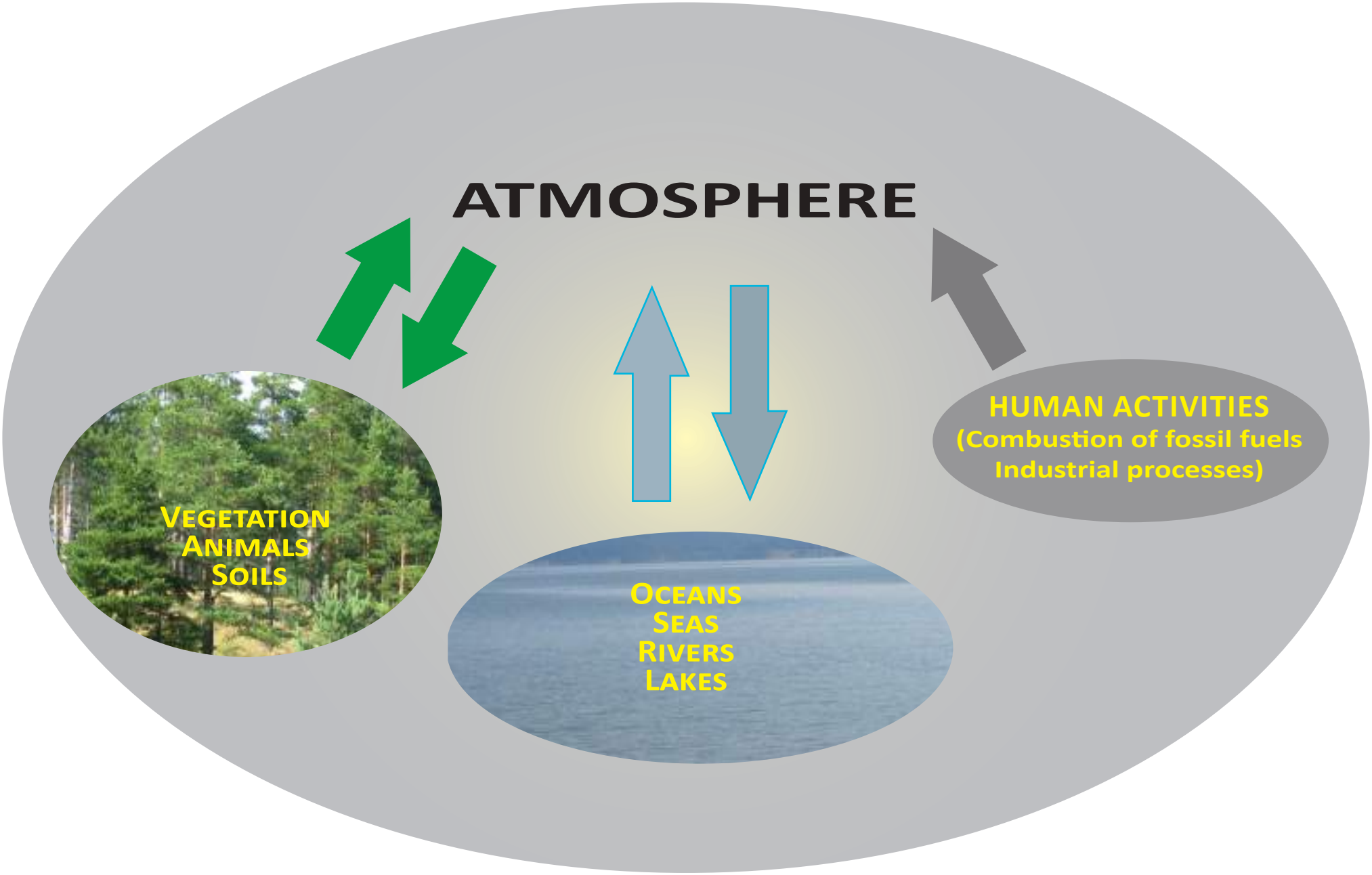
Atmosphere contains carbon mainly as CO_2 but also methane CH_4 and other carbon-containing gases. Sources of CO_2 in the atmosphere are burning of fossil fuels, decomposition of organic matter, respiration processes, volcanoes, hot springs, geysers, fermentation processes.

Living organisms contain carbon as proteins, fats, carbohydrates, etc. All these compounds are vital for maintaining life.

Natural waters (oceans, seas, lakes, rivers) contain dissolved carbonates.

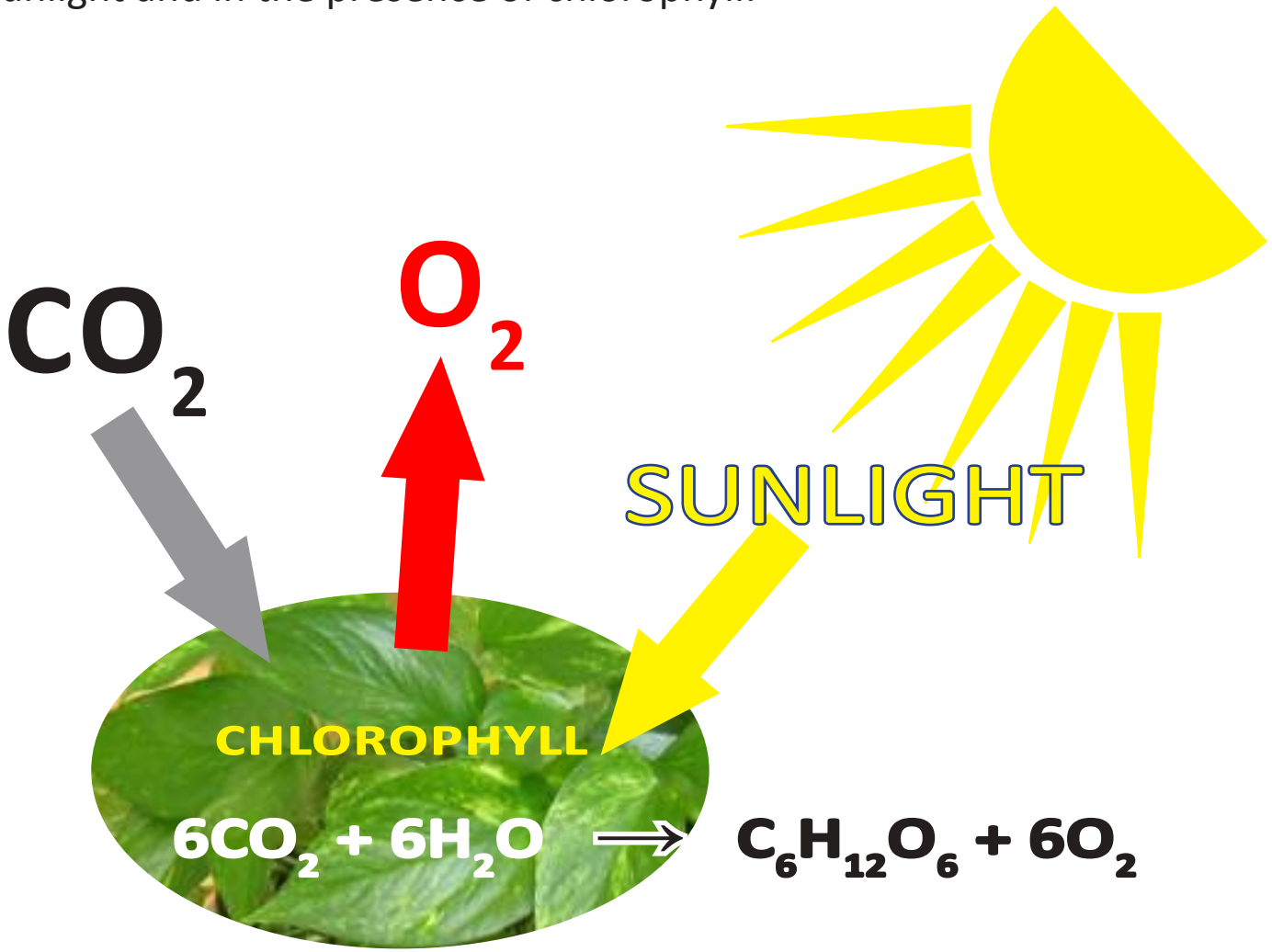
In the lithosphere carbon is found as minerals (for example $CaCO_3$, $MgCO_3$, etc.), fossil fuels, diamonds, graphite, coal, charcoal.

The carbon cycle involves natural processes as photosynthesis and respiration but is also affected by man.



THE CYCLYNG OF CARBON IN NATURE

The first stage of the carbon cycle is the conversion of the atmospheric CO_2 by green plants into organic compounds that build plants and are indispensable for their growth (glucose ($C_6H_{12}O_6$), carbohydrates, proteins, fats, etc.) The photosynthesis is a well known process going on only under the action of sunlight and in the presence of chlorophyll:



Animals eat plants, respire oxygen O_2 and liberate CO_2 that is available for the photosynthesis processes in plants. Carbon-containing compounds in plants that are not eaten by animals and the bodies of died animals decompose and either gases containing carbon are released into the atmosphere or carbon-containing products accumulate in the soil. The carbon in fossil fuels was stored up in the earth over millions of years. Once the fossil fuels have been recovered, processed and burnt, carbon dioxide $CO_2$is released back into the air.

Another major exchange of CO_2 occurs between oceans and the atmosphere. Atmospheric CO_2 enters water across the air-water surface. In the oceans and seas marine animals may convert carbon into $CaCO_3$. It builds up coastal sediments – rocks, shells, corals.

Man's activities may affect the carbon cycle in nature. An additional amount of CO_2 is pumped into the atmosphere because of the combustion of fossil fuels and the evolution of CO_2 in many industrial processes. As the amount of CO_2 in the atmosphere is less than 1 % even a small increase of the quantity of CO_2 in air may affect the climate. CO_2 is a greenhouse gas and is very important for the energy balance of the Earth. The global warming affects natural systems and agriculture. Additionally the increase of CO_2 in the atmosphere results in an increase of the amount of dissolved in natural waters CO_2. They become more acidic as carbonic acid forms. This may be destructive for the shells and the skeleton of marine organisms. The deforestation also affects negatively the cycling of carbon in nature.

As the changes in the amount of CO_2 in the atmosphere may affect the climate on our planet the World Meteorological Organization (WMO) monitors the CO_2 content in air.

CAN YOU ANSWER THESE QUESTIONS ?

1. How is carbon exchanged between the atmosphere, the biosphere and the hydrosphere?
2. Why is carbon cycling vital for all living organisms?
3. Why is Earth's climate affected even by small changes in the amount of CO_2 in the atmosphere?
4. What is global warming?
5. Can human activities perturb the cycling of carbon in nature?
6. Why does deforestation affect the carbon cycle?

PROJECTS

1. CARBON CYCLE IN NATURE

Read more about the carbon cycle in nature. Explain the environmental impact of the increasing amounts of carbon dioxide in the atmosphere.

2. CARBON DIOXIDE IN THE ATMOSPHERE

Discuss in class which are the possible activities to be realized in order to reduce the concentration of CO_2 in air.

3. FULLERENES

Search and share more information about the history of fullerenes, their exceptional properties and their possible applications.

4. GRAPHENE

Learn more about the new material graphene. Why is it innovative? Find out its most interesting uses.