A CASE STUDY ON
ALLOTROPES OF CARBON. ARE THERE ANY BUCKYBALLS?

by

Nadia BĂDOIU, Gymnasium School, Gura-Șuții, Romania

INTRODUCTION / BACKGROUND

Carbon (from Latin: carbo "coal") is the chemical element with symbol C and atomic number 6. As a member of group 14 on theperiodic table, it is nonmetallic and tetravalent — making four electrons available to form covalent chemical bonds. There are three naturally occurring isotopes, with ^{12}C and ^{13}C being stable, while ^{14}C is radioactive, decaying with a half-life of about 5,730 years. Carbon is one of the few elements known since antiquity.

There are several allotropes of carbon of which the best known are graphite, diamond, and amorphous carbon. The physical properties of carbon vary widely with the allotropic form. For example, diamond is highly transparent, while graphite is opaque and black. Diamond is the hardest naturally-occurring material known, while graphite is soft enough to form a streak on paper (hence its name, from the Greek word "γράφω" which means "to write"). Diamond has a very low electrical conductivity, while graphite is a very good conductor. Under normal conditions, diamond, carbon nanotube and graphene have the highest thermal conductivities ofall known materials.

All carbon allotropes are solids under normal conditions with graphite being the most thermodynamically stable form. They are chemically resistant and require high temperature to react even with oxygen. The most common oxidation state of carbon ininorganic compounds is +4, while +2 is found in carbon monoxide and other transition metal carbonyl complexes. The largest sources of inorganic carbon are limestones, dolomites and carbon dioxide, but significant quantities occur in organic deposits ofcoal, peat, oil and methane clathrates. Carbon forms more compounds than any other element, with almost ten million pure organic compounds described to date, which in turn are a tiny fraction of such compounds that are theoretically possible under standard conditions.

Carbon is the 15th most abundant element in the Earth's crust, and the fourth most abundant element in the universe by mass after hydrogen, helium, and oxygen. It is present in all known life forms, and in the human body carbon is the second most abundant element by mass (about 18.5%) after oxygen. This abundance, together with the unique diversity of organic compounds and their unusual polymer-forming ability at the temperatures commonly encountered on Earth, make this element the chemical.

HISTORY AND ETIMOLOGY

The English name *carbon* comes from the Latin *carbo* for coal and charcoal, whence also comes the French *charbon*, meaning charcoal. In German, Dutch and Danish, the names for carbon are *Kohlenstoff*, *koolstof* and *kulstof* respectively, all literally meaning coal-substance.

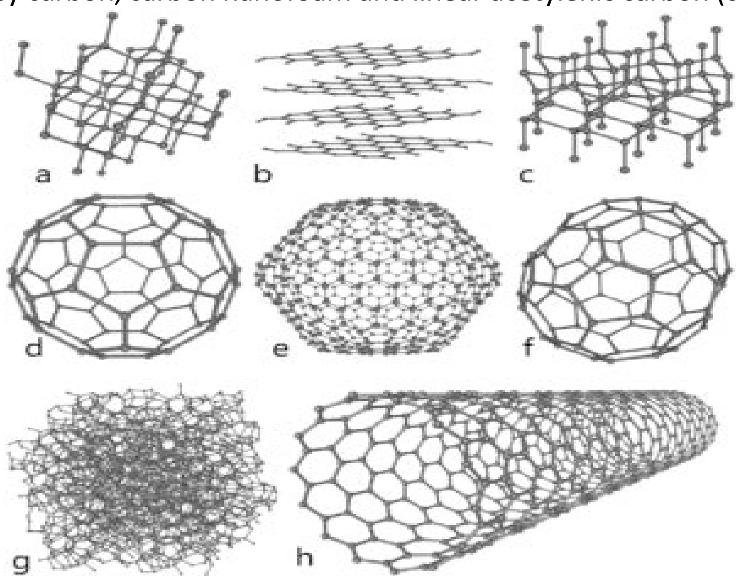
Carbon was discovered in prehistory and was known in the forms of soot and charcoal to the earliest human civilizations. Diamonds were known probably as early as 2500 BCE in China, while carbon in the form of charcoal was made around Roman times by the same chemistry as it is today, by heating wood in a pyramid covered with clay to exclude air.

In 1722, René Antoine Ferchault de Réaumur demonstrated that iron was transformed into steel through the absorption of some substance, now known to be carbon. In 1772, Antoine Lavoisier showed that diamonds are a form of carbon; when he burned samples of charcoal and diamond and found that neither produced any water and that both released the same amount of carbon dioxide per gram. In 1779, Carl Wilhelm Scheele showed that graphite, which had been thought of as a form of lead, was instead identical with charcoal but with a small admixture of iron, and that it gave "aerial acid" (his name for carbon dioxide) when oxidized with nitric acid. In 1786, the French scientists Claude Louis Berthollet, Gaspard Monge and C. A. Vandermonde confirmed that graphite was mostly carbon by oxidizing it in oxygen in much the same way Lavoisier had done with diamond. Some iron again was left, which the French scientists thought was necessary to the graphite structure. However, in their publication they proposed the name*carbone* (Latin *carbonum*) for the element in graphite which was given off as a gas upon burning graphite. Antoine Lavoisier then listed carbon as an element in his 1789 textbook.

A new allotrope of carbon, fullerene, that was discovered in 1985 includes nanostructured forms such as buckyballs and nanotubes. Their discoverers – Robert Curl, Harold Kroto and Richard Smalley – received the Nobel Prize in Chemistry in 1996. The resulting renewed interest in new forms lead to the discovery of further exotic allotropes, including glassy carbon, and the realization that "amorphous carbon" is not strictly amorphous.

ALLOTROPES

Atomic carbon is a very short-lived species and, therefore, carbon is stabilized in various multi-atomic structures with different molecular configurations called allotropes. The three relatively well-known allotropes of carbon are amorphous carbon, graphite, anddiamond. Once considered exotic, fullerenes are nowadays commonly synthesized and used in research; they includebuckyballs, carbon nanotubes, carbon nanobuds and nanofibers. Several other exotic allotropes have also been discovered, such as lonsdaleite glassy carbon, carbon nanofoam and linear acetylenic carbon (carbyne).



Some allotropes of carbon: a) diamond; b) graphite; c) lonsdaleite; d–f) fullerenes (C_{60}, C_{540}, C_{70}); g) amorphous carbon; h) carbon nanotube.

The amorphous form is an assortment of carbon atoms in a non-crystalline, irregular, glassy state, which is essentially graphite but not held in a crystalline macrostructure. It is present as a powder, and is the main constituent of substances such as charcoal, lampblack (soot) and activated carbon. At normal pressures carbon takes the form of graphite, in which each atom is bonded trigonally to three others in a plane composed of fused hexagonal rings, just like those in aromatic hydrocarbons. The resulting network is 2-dimensional, and the resulting flat sheets are stacked and loosely bonded through weak van der Waals forces. This gives graphite its softness and its cleaving properties (the sheets slip easily past one another). Because of the delocalization of one of the outer electrons of each atom to form a π-cloud, graphite conducts electricity, but only in the plane of each covalently bonded sheet. This results in a lower bulk electrical conductivity for carbon than for most metals. The delocalization also accounts for the energetic stability of graphite over diamond at room temperature.

At very high pressures carbon forms the more compact allotrope diamond, having nearly twice the density of graphite. Here, each atom is bonded tetrahedrally to four others, thus making a 3-dimensional network of puckered six-membered rings of atoms. Diamond has the same cubic structure as silicon and germanium and because of the strength of the carbon-carbon bonds, it is the hardest naturally occurring substance in terms of resistance to scratching. Contrary to the popular belief that *"diamonds are forever"*, they are in fact thermodynamically unstable under normal conditions and transform into graphite. However, due to a high activation energy barrier, the transition into graphite is as extremely slow at room temperature as to be unnoticeable. Under some conditions, carbon crystallizes as lonsdaleite. This form has a hexagonal crystal lattice where all atoms are covalently bonded. Therefore, all properties of lonsdaleite are close to those of diamond.

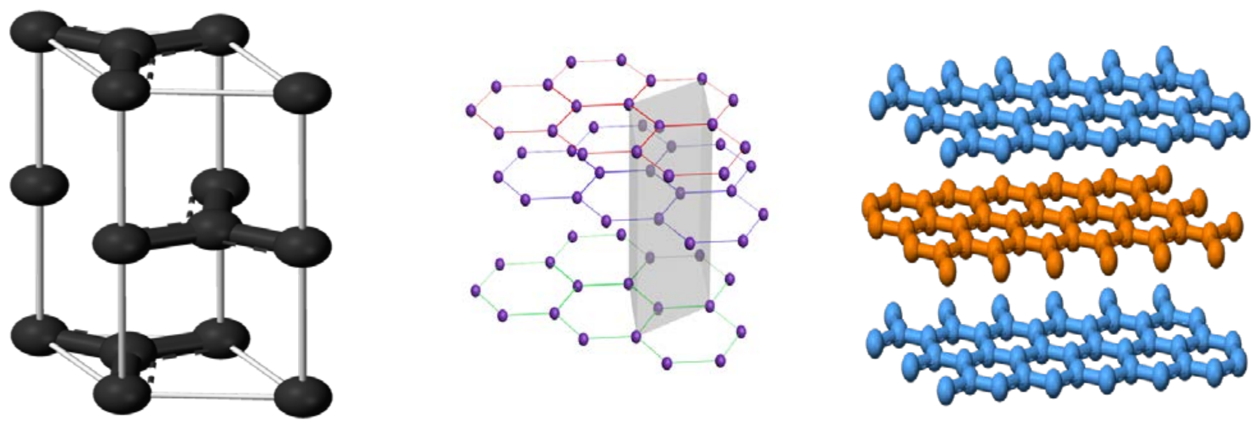
Fullerenes have a graphite-like structure, but instead of purely hexagonal packing, they also contain pentagons (or even heptagons) of carbon atoms, which bend the sheet into spheres, ellipses or cylinders. The properties of fullerenes (split intobuckyballs, buckytubes and nanobuds) have not yet been fully analyzed and represent an intense area of research innanomaterials. The names *"fullerene"* and *"buckyball"* are given after Richard Buckminster Fuller, popularizer of geodesic domes, which resemble the structure of fullerenes. The buckyballs are fairly large molecules formed completely of carbon bonded trigonally, forming spheroids (the best-known and simplest is the soccerball-shaped C_{60} buckminsterfullerene). Carbon nanotubes are structurally similar to buckyballs, except that each atom is bonded trigonally in a curved sheet that forms a hollow cylinder. Nanobuds were first reported in 2007 and are hybrid bucky tube/buckyball materials (buckyballs are covalently bonded to the outer wall of a nanotube) that combine the properties of both in a single structure.

Of the other discovered allotropes, carbon nanofoam is a ferromagnetic allotrope discovered in 1997. It consists of a low-density cluster-assembly of carbon atoms strung together in a loose three-dimensional web, in which the atoms are bonded trigonally in six- and seven-membered rings. It is among the lightest known solids, with a density of about 2 kg/m^3. Similarly, glassy carbon contains a high proportion of closed porosity, but contrary to normal graphite, the graphitic layers are not stacked like pages in a book, but have a more random arrangement. Linear acetylenic carbon has the chemical structure $-(C:::C)_n-$. Carbon in this modification is linear with *sp* orbital hybridization, and is a polymer with alternating single and triple bonds. This type of carbyne is of considerable interest to nanotechnology as its Young's modulus is forty times that of the hardest known material - diamond.

GRAPHITE

The mineral **graphite** /ˈɡræfaɪt/ is an allotrope of carbon. It was named by Abraham Gottlob Werner in 1789 from the Ancient Greekγράφω (*graphō*), "to draw/write", for its use in pencils, where it is commonly called **lead** (not to be confused with the metallic element lead). Unlike diamond (another carbon allotrope), graphite is an electrical conductor, a semimetal. It is, consequently, useful in such applications as arc lamp electrodes. Graphite is the most stable form of carbon under standard conditions. Therefore, it is used in thermo-chemistry as the standard state for defining the heat of formation of carbon compounds. Graphite may be considered the highest grade of coal, just above anthracite and alternatively called meta-anthracite, although it is not normally used as fuel because it is difficult to ignite.

Graphite has a layered, planar structure. In each layer, the carbon atoms are arranged in a honeycomb lattice with separation of 0.142 nm, and the distance between planes is 0.335 nm. The two known forms of graphite, *alpha* (hexagonal) and *beta* (rhombohedral), have very similar physical properties, except that the graphene layers stack slightly differently. The hexagonal graphite may be either flat or buckled. The alpha form can be converted to the beta form through mechanical treatment and the beta form reverts to the alpha form when it is heated above 1300 °C.



Graphite's unit cell

The acoustic and thermal properties of graphite are highly anisotropic, since phonons propagate quickly along the tightly-bound planes, but are slower to travel from one plane to another.

Graphite can conduct electricity due to the vast electron delocalization within the carbon layers (a phenomenon called aromaticity). These valence electrons are free to move, so are able to conduct electricity. However, the electricity is primarily conducted within the plane of the layers. The conductive properties of powdered graphite allowed its use as a semiconductor substitute in early carbon microphones.

Graphite and graphite powder are valued in industrial applications for their self-lubricating and dry lubricating properties. There is a common belief that graphite's lubricating properties are solely due to the loose interlamellar coupling between sheets in the structure. However, it has been shown that in a vacuum environment (such as in technologies for use in space), graphite is a very poor lubricant. This observation led to the hypothesis that the lubrication is due to the presence of fluids between the layers, such as air and water, which are naturally adsorbed from the environment. This hypothesis has been refuted by studies showing that air and water are not absorbed. Recent studies suggest that an effect called superlubricity can also account for graphite's lubricating properties. The use of graphite is limited by its tendency to facilitate pitting corrosion in some stainless steel, and to promote galvanic corrosion between dissimilar metals (due to its electrical conductivity). It is also corrosive to aluminium in the presence of moisture. For this reason, the US Air Force banned its use as a lubricant in aluminium aircraft, and discouraged its use in aluminium-containing automatic weapons. Even graphite pencil marks on aluminium parts may facilitate corrosion. Another high-temperature lubricant, hexagonal boron nitride, has the same molecular structure as graphite. It is sometimes called *white graphite*, due to its similar properties. When a large number of crystallographic defects bind these planes together, graphite loses its lubrication properties and becomes what is known as pyrolytic graphite. It is also highly anisotropic, and diamagnetic, thus it will float in mid-air above a strong magnet. If it is made in a fluidized bed at 1000–1300 °C then it is isotropic turbostratic, and is used in blood contacting devices like mechanical heart valves and is called (pyrolytic carbon), and is not diamagnetic. Pyrolytic graphite, and pyrolytic carbon are often confused but are very different materials. Natural and crystalline graphites are not often used in pure form as structural materials, due to their shear-planes, brittleness and inconsistent mechanical properties.

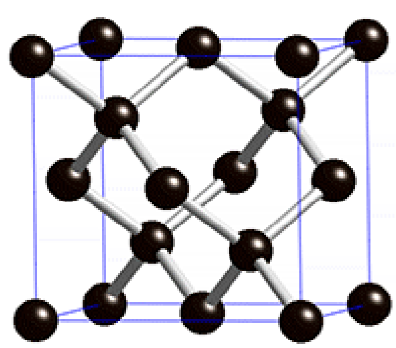
Graphite (carbon) fiber and carbon nanotubes are also used in carbon fiber reinforced plastics, and in heat-resistant composites such as reinforced carbon-carbon (RCC). Commercial structures made from carbon fiber graphite composites include fishing rods, golf club shafts, bicycle frames, sports car body panels, the fuselage of the Boeing 787 Dreamliner and pool cue sticks and have been successfully employed in reinforced concrete, The mechanical properties of carbon fiber graphite-reinforced plastic composites and grey cast iron are strongly influenced by the role of graphite in these materials. In this context, the term "(100%) graphite" is often loosely used to refer to a pure mixture of carbon reinforcement and resin, while the term "composite" is used for composite materials with additional ingredients. Modern smokeless powder is coated in graphite to prevent the buildup of static charge. Graphite has been used in at least three radar absorbent materials. It was mixed with rubber in Sumpf and Schornsteinfeger, which were used on U-boat snorkels to reduce theirradar cross section. It was also used in tiles on early F-117 Nighthawks.

DIAMOND

In mineralogy, **diamond** (from the ancient Greek αδάμας – *adámas* "unbreakable") is a metastable allotrope of carbon, where the carbon atoms are arranged in a variation of the face-centered cubic crystal structure called a diamond lattice. Diamond is less stable than graphite, but the conversion rate from diamond to graphite is negligible at ambient conditions. Diamond is renowned as a material with superlative physical qualities, most of which originate from the strong covalent bonding between its atoms. In particular, diamond has the highest hardness and thermal conductivity of any bulk material. Those properties determine the major industrial application of diamond in cutting and polishing tools and the scientific applications in diamond knives and diamond anvil cells.

Diamond has remarkable optical characteristics. Because of its extremely rigid lattice, it can be contaminated by very few types of impurities, such as boron and nitrogen. Combined with wide transparency, this results in the clear, colorless appearance of most natural diamonds. Small amounts of defects or impurities (about one per million of lattice atoms) color diamond blue (boron), yellow (nitrogen), brown (lattice defects), green (radiation exposure), purple, pink, orange or red. Diamond also has relatively high optical dispersion (ability to disperse light of different colors), which results in its characteristic luster. Excellent optical and mechanical properties, notably unparalleled hardness and durability, make diamond the most popular gemstone.

Most natural diamonds are formed at high temperature and pressure at depths of 140 to 190 kilometers (87 to 120 mi) in the Earth's mantle. Carbon-containing minerals provide the carbon source, and the growth occurs over periods from 1 billion to 3.3 billion years (25% to 75% of the age of the Earth). Diamonds are brought close to the Earth's surface through deep volcanic eruptions by a magma, which cools into igneous rocks known as kimberlites and lamproites. Diamonds can also be produced synthetically in a high-pressure high-temperature process which approximately simulates the conditions in the Earth mantle. An alternative and completely different growth technique is chemical vapor deposition (CVD). Several non-diamond materials, which include cubic zirconia andsilicon carbide and are often called diamond simulants, resemble diamond in appearance and many properties. Special gemological techniques have been developed to distinguish natural and synthetic diamonds and diamond simulants.



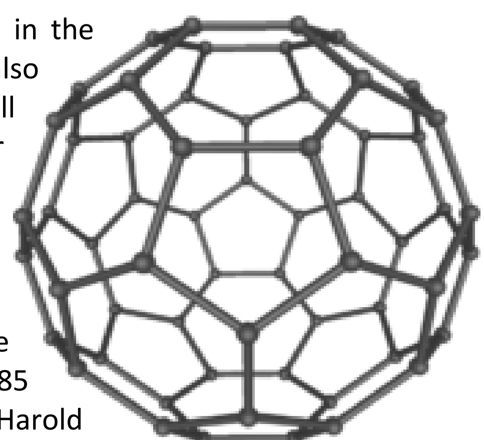
A diamond is a transparent crystal of tetrahedrally bonded carbon atoms in a covalent network lattice (sp^3) that crystallizes into the diamond lattice which is a variation of the face centered cubic structure. Diamonds have been adapted for many uses because of the material's exceptional physical characteristics. Most notable are its extreme hardness and thermal conductivity (900-2,320 $W{\cdot}m^{-1}{\cdot}K^{-1}$), as well as wide bandgap and high optical dispersion. Above 1,700 °C (1,973 K / 3,583 °F) in vacuum or oxygen-free atmosphere, diamond converts to graphite; in air, transformation starts at ~700 °C. Diamond's ignition point is 720 – 800 °C in oxygen and 850 - 1,000 °C in air. Naturally occurring diamonds have a density ranging from 3.15-3.53 g/cm^3, with pure diamond close to 3.52 g/cm^3. The chemical bonds that hold the carbon atoms in diamonds together are weaker than those in graphite. In diamonds, the bonds form an inflexible three-dimensional lattice, whereas in graphite, the atoms are tightly bonded into sheets, which can slide easily over one another, making the overall structure weaker.

Diamond is the hardest known natural material on the Mohs scale of mineral hardness, where hardness is defined as resistance to scratching and is graded between 1 (softest) and 10 (hardest). Diamond has a hardness of 10 (hardest) on this scale. Diamond's hardness has been known since antiquity, and is the source of its name.

Other specialized applications also exist or are being developed, including use as semiconductors: some blue diamonds are natural semiconductors, in contrast to most diamonds, which are excellent electrical insulators. The conductivity and blue color originate from boron impurity. Boron substitutes for carbon atoms in the diamond lattice, donating a hole into the valence band. Substantial conductivity is commonly observed in nominally undoped diamond grown by chemical vapor deposition. This conductivity is associated with hydrogen-related species adsorbed at the surface, and it can be removed by annealing or other surface treatments.

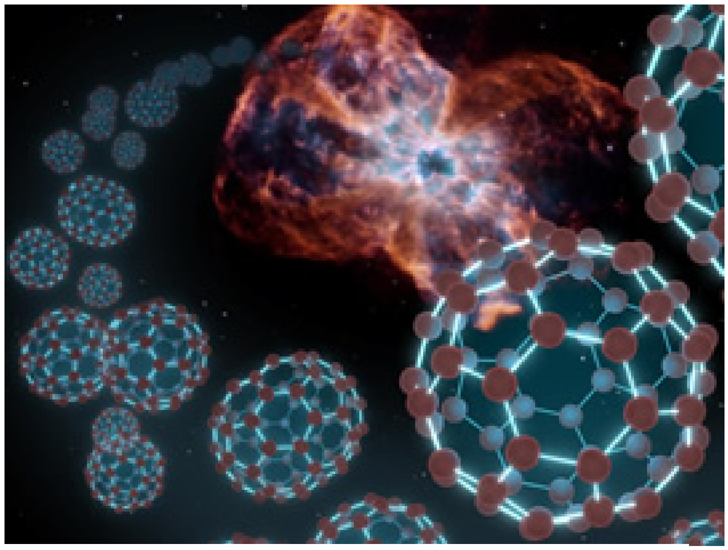
Diamonds are naturally lipophilic and hydrophobic, which means the diamonds' surface cannot be wet by water but can be easily wet and stuck by oil. This property can be utilized to extract diamonds using oil when making synthetic diamonds. However, when diamond surfaces are chemically modified with certain ions, they are expected to become sohydrophilic that they can stabilize multiple layers of water ice at human body temperature.

BUCKYBALLS



A **fullerene** is any molecule composed entirely of carbon, in the form of a hollow sphere, ellipsoid or tube. Spherical fullerenes are also called **buckyballs**, and they resemble the balls used in football (soccer). Cylindrical ones are called carbon nanotubes or buckytubes. Fullerenes are similar in structure to graphite, which is composed of stacked graphene sheets of linked hexagonal rings; but they may also contain pentagonal (or sometimes heptagonal) rings.

The first fullerene molecule to be discovered, and the family's namesake, buckminsterfullerene (C_{60}), was prepared in 1985 by Richard Smalley, Robert Curl, James Heath, Sean O'Brien, and Harold Krotoat Rice University. The name was homage to Buckminster Fuller, whose geodesic domes it resembles. The structure was also identified some five years earlier by Sumio Iijima, from an electron microscope image, where it formed the core of a "bucky onion." Fullerenes have since been found to occur in nature. More recently, fullerenes have been detected in outer space. According to astronomer Letizia Stanghellini, "It’s possible that buckyballs from outer space provided seeds for life on Earth."

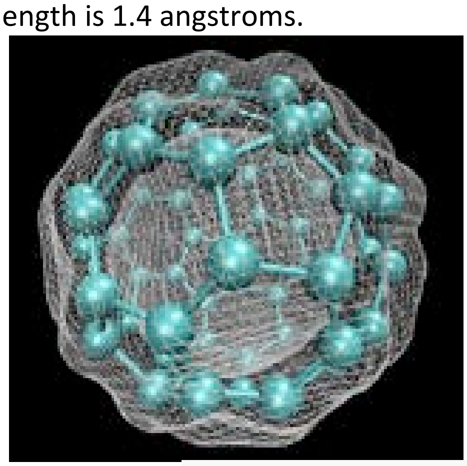

NASA's Spitzer Space Telescope has at last found Buckyballs in space.
Image Credit: NASA/JPL-Caltech

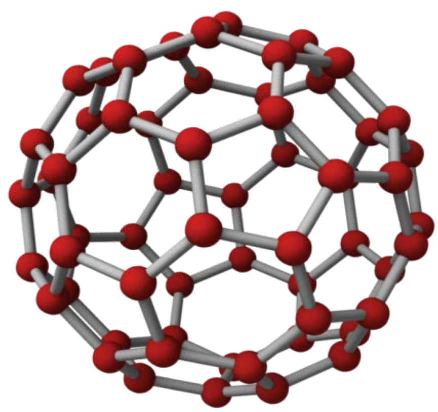
The discovery of fullerenes greatly expanded the number of known carbon allotropes, which until recently were limited to graphite, diamond, and amorphous carbon such as soot and charcoal. Buckyballs and buckytubes have been the subject of intense research, both for their unique chemistry and for their technological applications, especially in materials science, electronics, and nanotechnology.

Buckminsterfullerene (C_{60}) was named after Richard Buckminster Fuller, a noted architectural modeler who popularized the geodesic dome. Since buckminsterfullerenes have a shape similar to that sort of dome, the name was thought appropriate.[16] As the discovery of the fullerene family came *after* buckminsterfullerene, the shortened name 'fullerene' is used to refer to the family of fullerenes. The suffix "ene" indicates that each C atom is covalently bonded to three others (instead of the maximum of four), a situation that classically would correspond to the existence of bonds involving two pairs of electrons ("double bonds").

DisneyEpcotCenter- Geodesic Dome designed by R. Buckminister Fuller

Buckminsterfullerene is the smallest fullerene molecule containing pentagonal and hexagonal rings in which no two pentagons share an edge (which can be destabilizing, as in pentalene). It is also the most common in terms of natural occurrence, as it can often be found in soot. The structure of C_{60} is a truncated icosahedron, which resembles an association football ball of the type made of twenty hexagons and twelve pentagons, with a carbon atom at the vertices of each polygon and a bond along each polygon edge. The van der Waals diameter of a C_{60} molecule is about 1.1 nanometers (nm).[23] The nucleus to nucleus diameter of a C_{60} molecule is about 0.71 nm. The C_{60} molecule has two bond lengths. The 6:6 ring bonds (between two hexagons) can be considered "double bonds" and are shorter than the 6:5 bonds (between a hexagon and a pentagon). Its average bond length is 1.4 angstroms.

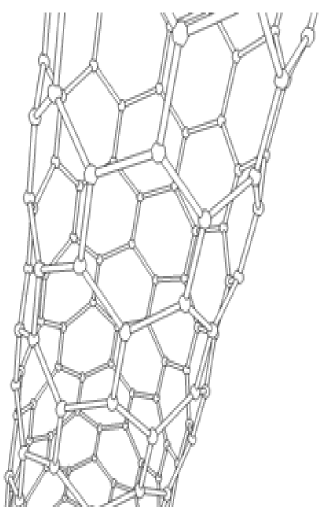




C_{60} with isosurface of ground state electron density as calculated with DFT

While past cancer research has involved radiation therapy, photodynamic therapy is important to study because breakthroughs in treatments for tumor cells will give more options to patients with different conditions. More recent experiments using HeLa cells in cancer research involves the development of new photosensitizerswith increased ability to be absorbed by cancer cells and still trigger cell death. It is also important that a new photosensitizer does not stay in the body for a long time to prevent unwanted cell damage. Fullerenes can be made to be absorbed by HeLa cells. The C_{60} derivatives can be delivered to the cells by using the functional groups L-phenylalanine, folic acid, and L-arginine among others. The purpose for functionalizing the fullerenes is to increase the solubility of the molecule by the cancer cells. Cancer cells take up these molecules at an increased rate because of an upregulation of transporters in the cancer cell, in this case amino acid transporters will bring in the L-arginine and L-phenylalanine functional groups of the fullerenes. Once absorbed by the cells, the C_{60} derivatives would react to light radiation by turning molecular oxygen intoreactive oxygen which triggers apoptosis in the HeLa cells and other cancer cells that can absorb the fullerene molecule. This research shows that a reactive substance can target cancer cells and then be triggered by light radiation, minimizing damage to surrounding tissues while undergoing treatment.
When absorbed by cancer cells and exposed to light radiation, the reaction that creates reactive oxygen damages the DNA, proteins, and lipids that make up the cancer cell. This cellular damage forces the cancerous cell to go through apoptosis, which can lead to the reduction in size of a tumor. Once the light radiation treatment is finished the fullerene will reabsorb the free radicals to prevent damage of other tissues. Since this treatment focuses on cancer cells it is a good option for patients whose cancer cells are within reach of light radiation. As this research continues into the future it will be able to penetrate deeper into the body and more effectively absorbed by cancer cells.

CARBON NANOTUBES (BUCKYTUBES)



Nanotubes are cylindrical fullerenes. These tubes of carbon are usually only a few nanometres wide, but they can range from less than a micrometer to several millimeters in length. They often have closed ends, but can be open-ended as well. There are also cases in which the tube reduces in diameter before closing off. Their unique molecular structure results in extraordinary macroscopic properties, including high tensile strength, high electrical conductivity, high ductility, high heat conductivity, and relative chemical inactivity (as it is cylindrical and "planar" — that is, it has no "exposed" atoms that can be easily displaced). One proposed use of carbon nanotubes is in paper batteries, developed in 2007 by researchers at Rensselaer Polytechnic Institute. Another highly speculative proposed use in the field of space technologies is to produce high-tensile carbon cables required by a space elevator.

OBJECTIVES

The lesson activities are designed for the *VIIIth form students*, and try to develop student's knowledge and practical skills related to allotropes of carbon. In addition, the proposed activities involve direct exchanges of ideas and experience, offering also an investigative approach.

The objectives consisted of:

- increasing the knowledge of young students related to Science topics;
- training the young students on recent scientific findings;
- training the young people to express their views on various Science issues;
- acquiring (by students) of investigative capacities and skills.

From the scientific point of view, the lesson activities allow students to learn about the defined characteristics of:

- the allotropes of carbon.
- the structure of buckyball.
- the application areas of buckyballs and carbon nanotubes.
- the different covalent bond structures of carbon.
- the crystal structure of allotropes of carbon.

LEARNING RESULTS

When acquiring the information and after realizing the activities, students are able to:

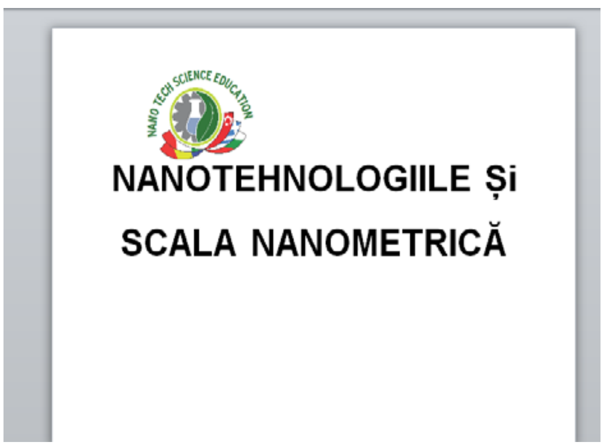
- understand the allotropes of carbon;
- make connections between the presented structures (carbon nanotube and buckyball) and nanotechnology;
- acquire knowledge about the variation of physical properties of a certain chemical substances, according to its different molecular structure types;
- identify the consequences of applying nanotechnologies to human health, environment and society;
- retrieve specific information in the proposed websites (especially the information from *NTSE Virtual Lab* and *NTSE Repository*);
- analyze selected information in relation to the proposed questions;
- work in groups to experience and make practical activities (models which imitate the allotropes of carbon);
- present group conclusions in the front of the teacher and students.

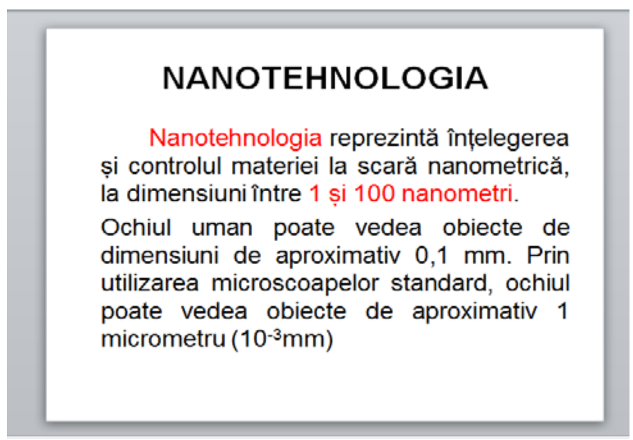
CLASSROOM MANAGEMENT & SEQUENCE OF EVENTS

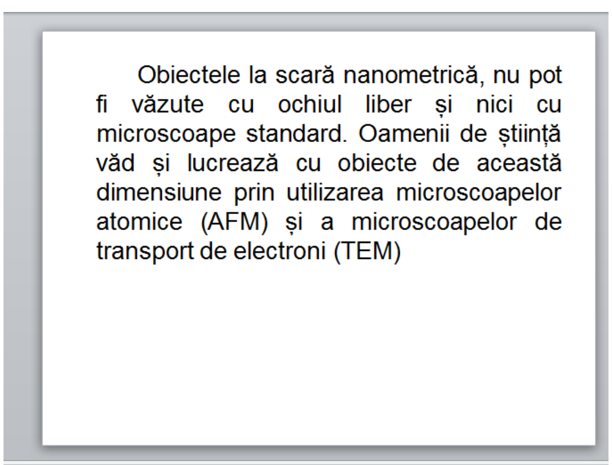
The proposed activities provide the opportunity to explore and understand the crystal structures of allotropes of carbon. Students find out the differences and similarities of allotropes of carbon. Mainly, the lessons introduce the *buckyball* and *carbon nanotubes* structures and their application areas.

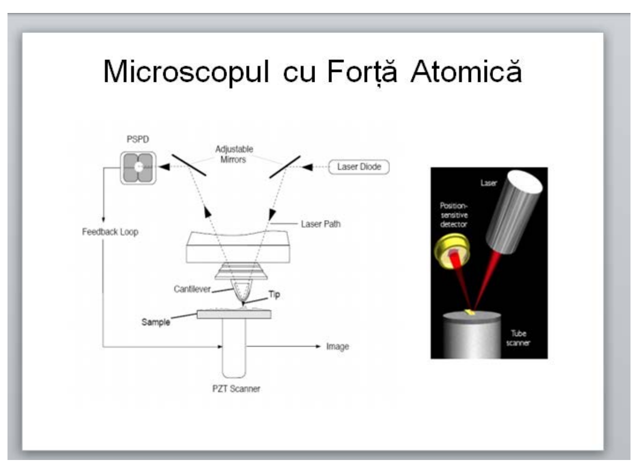
1. Introducing the concepts of Nanotechnology and Nanoscale, in particular

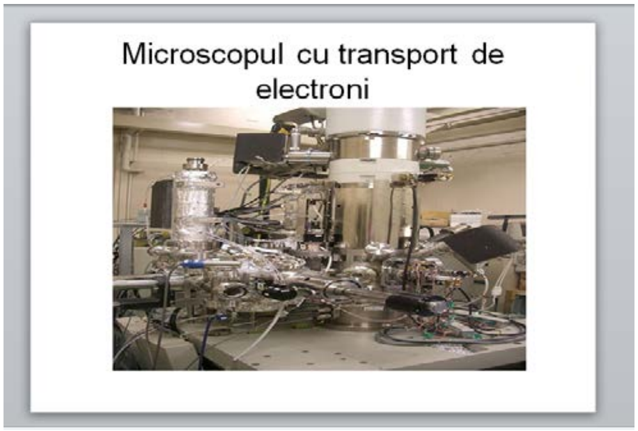
From the beginning, the students watch a *ppt presentation* (prepared by the teacher, in Romanian language - see below), in which the concepts of *Nanotechnology* and *Nanoscale* are introduced. In the end, the young students assist to the educational videoclip related to *Understanding Nanoscale* (from *NTSE Virtual Lab*): http://vlab.ntse-nanotech.eu/NanoVirtualLab/, and also the animation concerning *The Scale of the Universe 2*, illustrated at: http://htwins.net/scale2/.

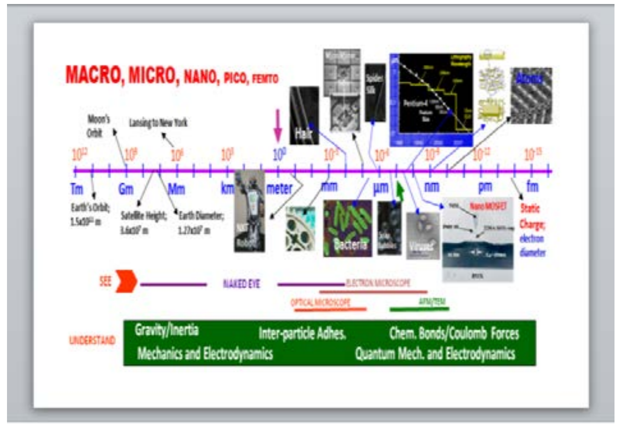


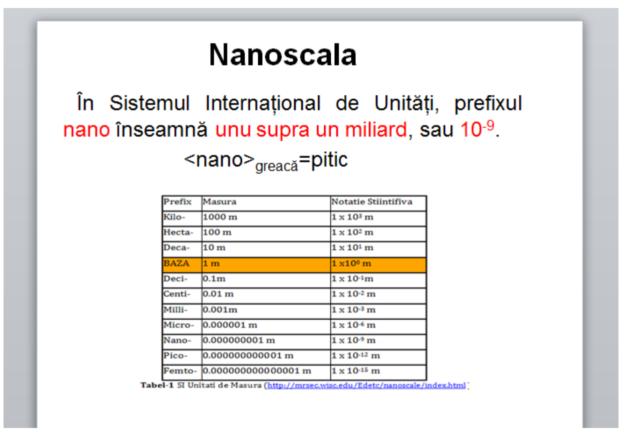






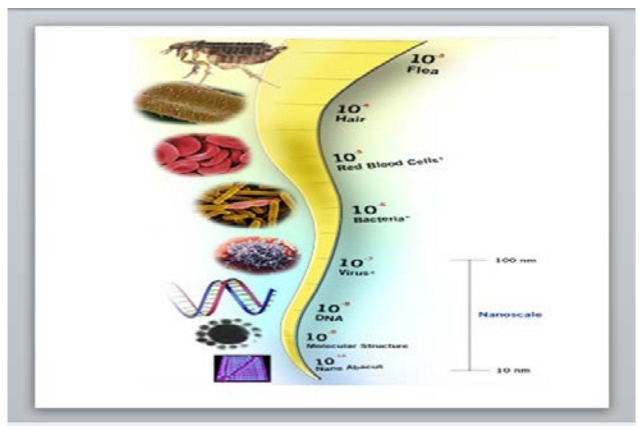




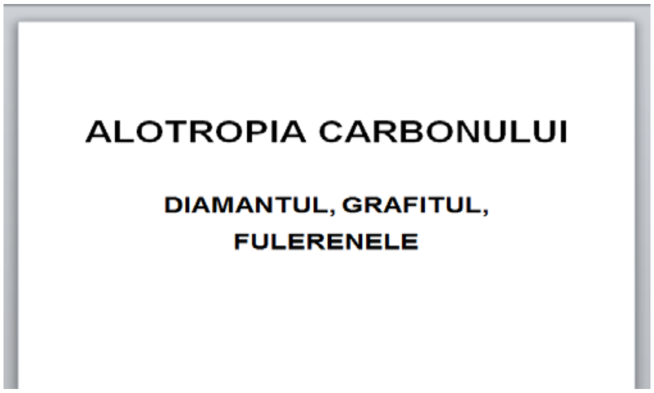


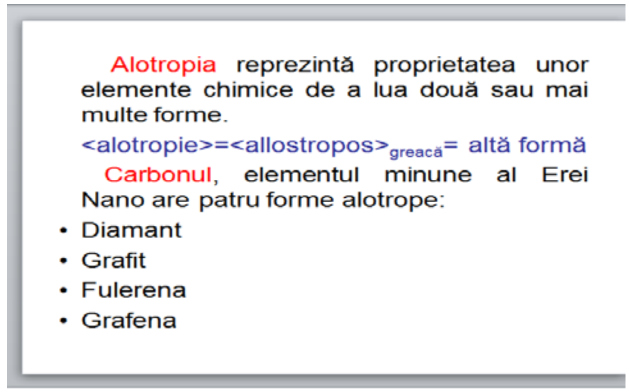
Prefix	Masura	Notatie Stiintifiva
Kilo-	1000 m	1×10^{3} m
Hecta-	100 m	1×10^{2} m
Deca-	10 m	1×10^{1} m
BAZA	1 m	1×10^{0} m
Deci-	0.1m	1×10^{-1}m
Centi-	0.01 m	1×10^{-2} m
Milli-	0.001m	1×10^{-3} m
Micro-	0.000001 m	1×10^{-6} m
Nano-	0.000000001 m	1×10^{-9} m
Pico-	0.000000000001 m	1×10^{-12} m
Femto-	0.000000000000001 m	1×10^{-15} m

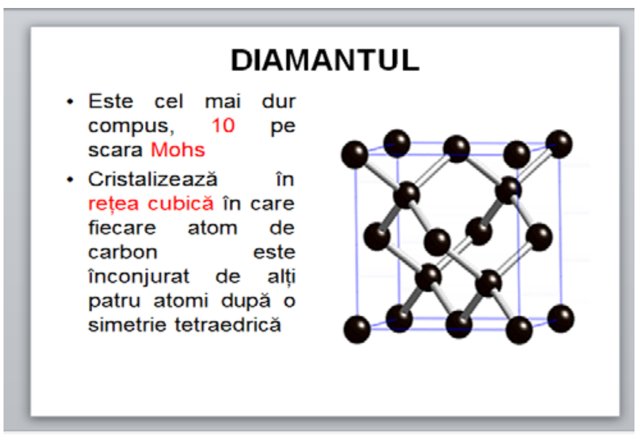
Tabel-1 SI Unitati de Masura (http://mrsec.wisc.edu/Edetc/nanoscale/index.html)

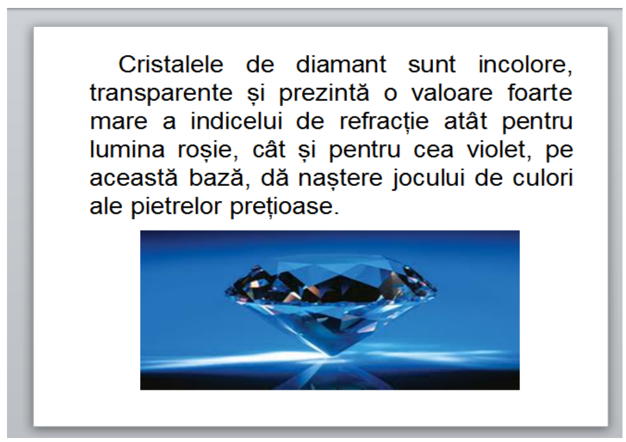


In the second part, the teacher presents the allotropes of carbon (continuing on using the *ppt presentation*, in Romanian), and asks the young students about: *What represents the allotropes of carbon?* and *Do you know about other famous allotropes in the nature?*





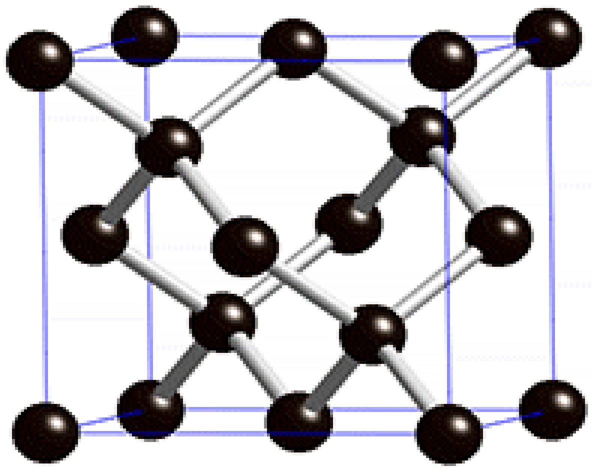




2. Activity 1

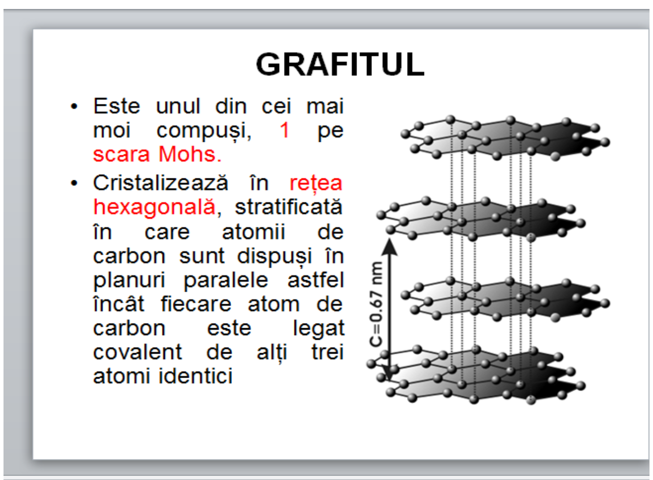
After the presentation of *diamond*, the young students are asked to solve a first task:

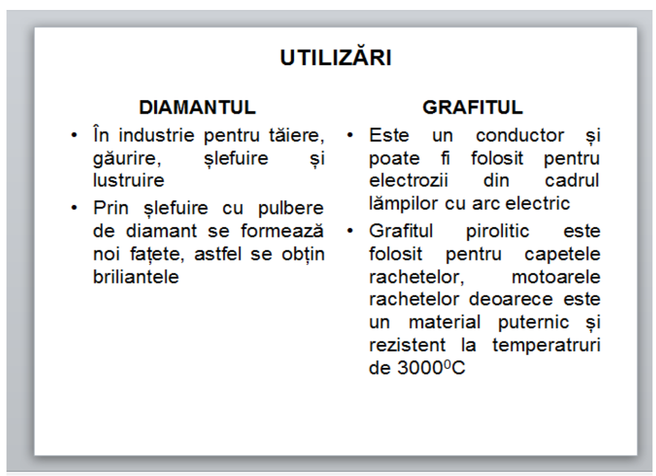
“*Build your own diamond model using equal length sticks and modeling clay. You can see the following figure, shown below as a model. You can use the modeling clay to symbolize carbon atoms and the sticks to symbolize the bonds in between.*”



Diamond

The presentation continues with the slides that illustrate the *graphite*.

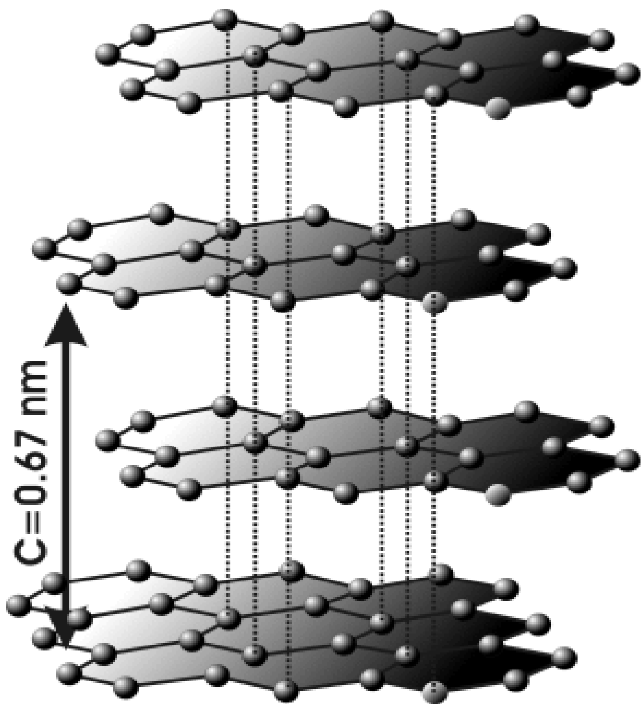




3. Activity 2

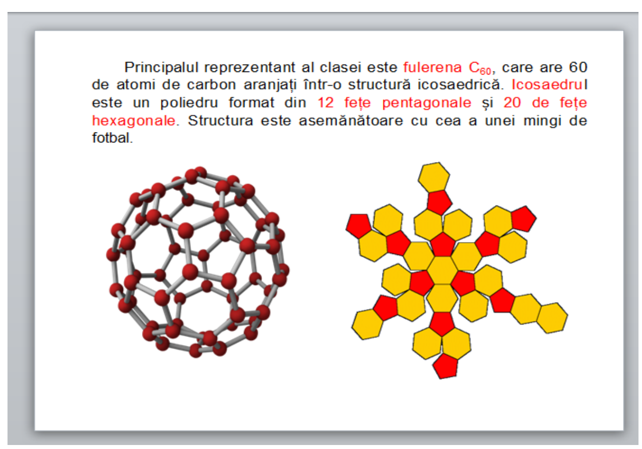
After the presentation of *graphite*, the young students are asked to solve a second task:

***"**Build your own graphite model, using equal length sticks and modeling clay. You can see the following figure, shown below as a model. You can use the modeling clay to symbolize carbon atoms and the sticks to symbolize the bonds in between."*



Graphite

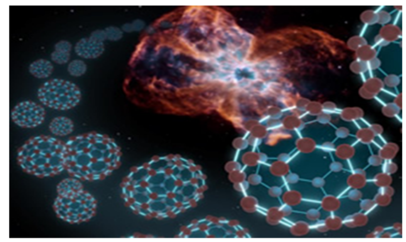
The presentation continues with the slides that illustrate the *buckyball*.



Fulerena de tip Buckyball prezintă proprietăți fizice interesante: este rezistentă la şoc, extrem de robustă şi foarte stabilă, capabilă de a supravieţui condiţiilor extreme de temperatură din spaţiul cosmic.

Are capacitate bună de a absorbi atomi de hidrogen; ea poate deveni un mediu bun de stocare a hidrogenului şi, prin urmare, un factor cheie în dezvoltarea de baterii noi non-poluante pentru automobile.

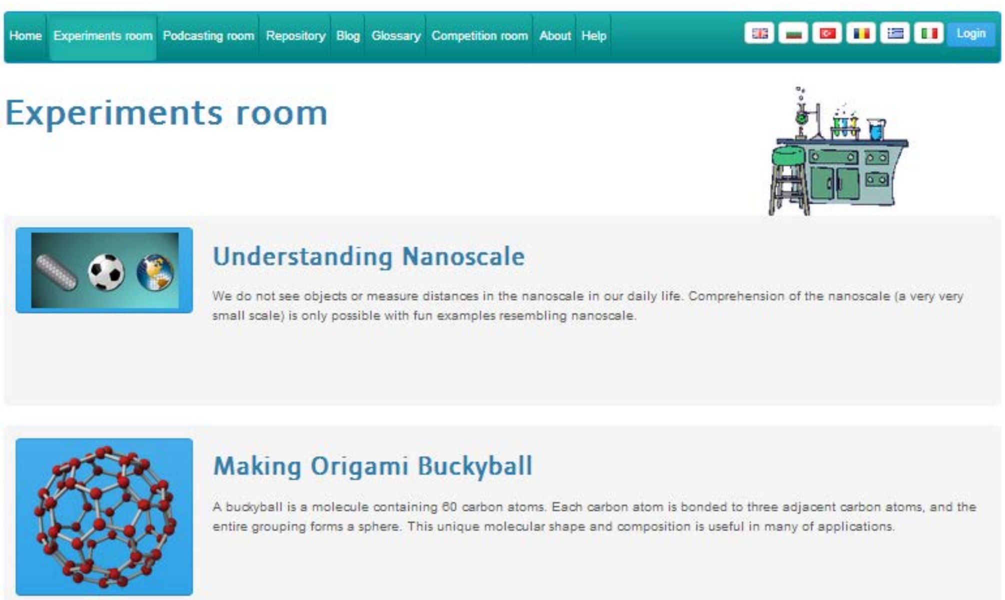
În anul 2010 astronomii NASA au descoperit în spațiu cu ajutorul Telescopului Spațial Spitzer astfel de structuri moleculare de carbon.



4. Activity 3

After the presentation of *buckyball*, the young students are asked to solve a third task:

"*Build your own buckyball model, using a hexagonal prototype printed on the special cardboard, prepared for you by the teacher. Simultaneously, you are invited to watch and notice another method for building a buckyball model, from the NTSE Virtual Lab - Making Origami Buckyballs -* http://vlab.ntse-nanotech.eu/NanoVirtualLab/."



The teacher must offer to the students, the necessary time to solve the proposed tasks.

In the final part, the students are invited to test their knowledge.

5. Activity 4 (Check / Test your knowledge!)

A. Write (T) True or (F) False for the statements below:
(   ) 1 - Graphite is a conductor and can be used as the material in the electrodes of an electric arc lamp.
(   ) 2 - Allotropes have different physical properties and the same chemical properties.
(   ) 3 - The atoms forming allotropes have the same kind of bonding in between, but in different manners.
(   ) 4 - Diamond is a hollow cluster of 60 carbon atoms shaped like a soccer ball.

B. Fill in the blanks with the appropriate expression:
1 - Buckyball is a ………………………… molecule with the formula: C_{60}.
2 - ………………………… are different structural modifications of an element.
3 - ………………………… is the hardest natural mineral.

RESOURCES
Procedural resources:

- methods and processes: presentation, conversation, observation, explication, experimenting, modeling, discussing;
- form of organization: groups (during the modeling activities), individual (frontal).

Material resources: video-projector, flipcharts, media texts, PCs, Internet, sticks and modeling clay.

PROCESS FINALIZATION AND ASSESSMENT

For finalizing the whole process, the test specified at *Activity 4* is used. Discussions are also important to clarify the misunderstandings and strength the acquired knowledge. All the models realized by the young students are presented (preferable by each group - one group present the *diamond model*, one group the *graphite model* and another, the *buckyball model*).

After the activities, the young students are asked to search for videos and documents related to the allotropes of carbon (and especially, buckyballs), in the *NTSE Repository* (http://ntse.ssai.valahia.ro/). In an extra-lesson, the main concepts will be reviewed, using the students' findings from the *NTSE Repository*.

Additionally to the test specified at *Activity 4*, when making the evaluation of the young students, the teachers can take into consideration other items concerning:

- how the students understand the proposed / introduced concepts and terms;

- how the students experience and collaborate in the process of models designing;
- how the students participate and answer in different moments of the activities;
- how the students use the allocated time;
- how the students use the technology for documentation / justification.

IMPACT ON STUDENTS

At student' level, the impact is specific, embracing the form of maximizing his / her involvement in the proposed activities, with a view to multiply the understanding of the real world, in particular, on the importance of Nanotechnology, on the clear perception of the Nanoscale, and on the basic knowledge referred to scientific issues, like the allotropes of carbon. At the same time, the practical abilities (experiencing, modeling) done by collaborating inside the working group, offer an important social impact.

STUDENTS' FEEDBACK

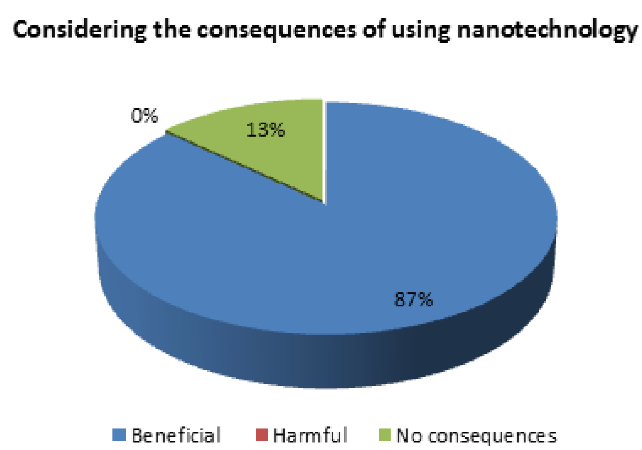
Expressed feedback:

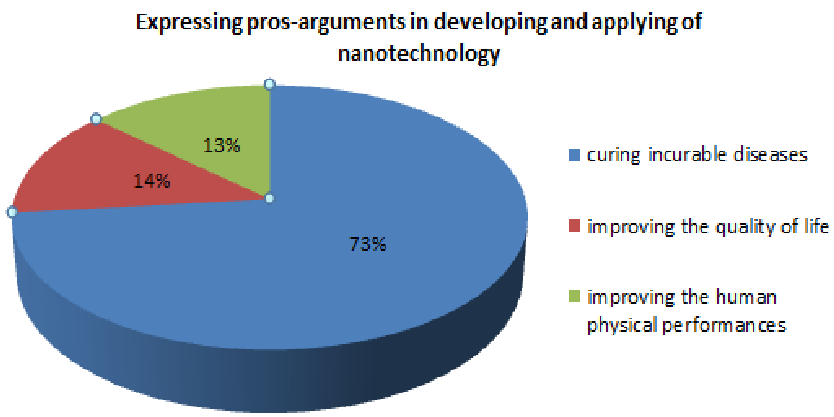
- real scientific issues have been presented;
- opportunity to work in groups and know better the colleagues;
- possibility to make a scientific documentation using the recommended websites;

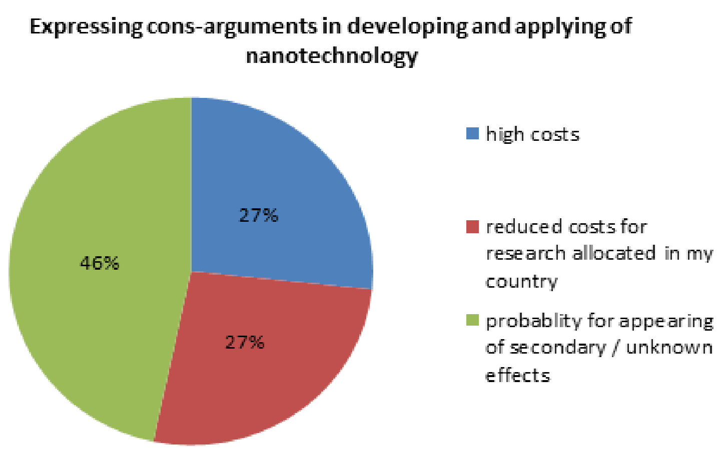
All the young students expressed their enthusiasm due to the fact that they had been involved in activities that mixed the theory with practice. All of them said that they learned new and interesting things and they were very motivated (permanently) by the teacher, during the whole lesson.

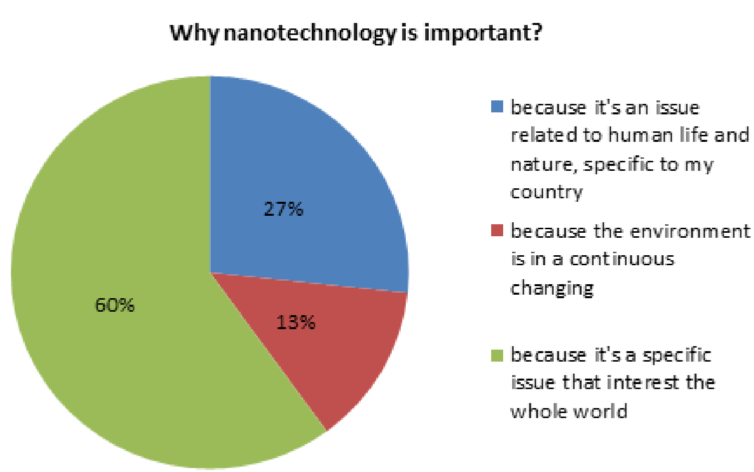
Processed feedback (graphical results):

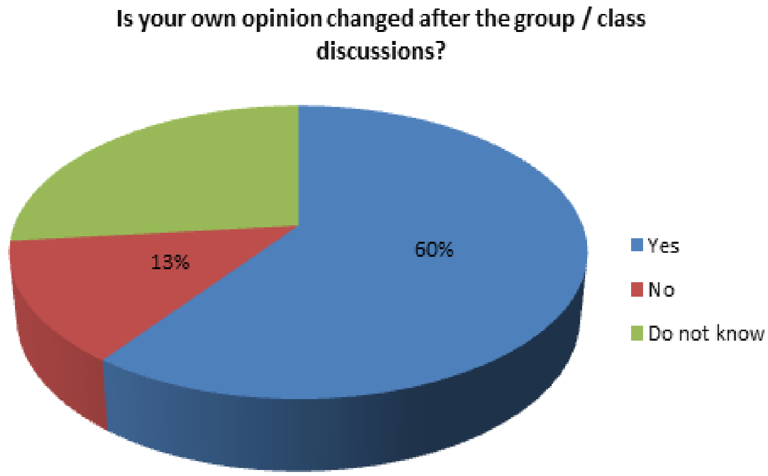
The young students were asked to fill in a questionnaire, with the view to elaborate a graphical image on some specific issues. Some results are presented in the following graphs.

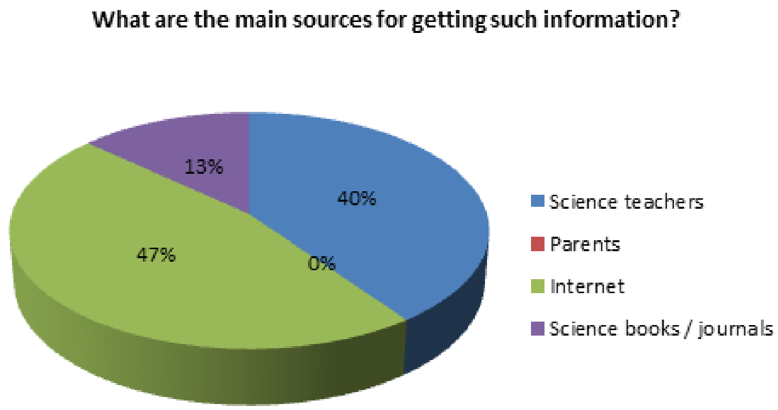



Expressing pros-arguments in developing and applying of nanotechnology
13%
14%
73%
curing incurable diseases
improving the quality of life
improving the human physical performances


Expressing cons-arguments in developing and applying of nanotechnology
27%
46%
27%
high costs
reduced costs for research allocated in my country
probablity for appearing of secondary / unknown effects


Why nanotechnology is important?
27%
60%
13%
because it's an issue related to human life and nature, specific to my country
because the environment is in a continuous changing
because it's a specific issue that interest the whole world





CONCLUSION

During the proposed activities, the young students were invited to participate in the experiencing and modeling tasks, but also to discuss, debate and conclude. The lessons' objectives were fulfilled, from the scientific point of view - on the one hand, but also from the social point of view - on the other hand, collaboration and cooperation being two very present major issues.

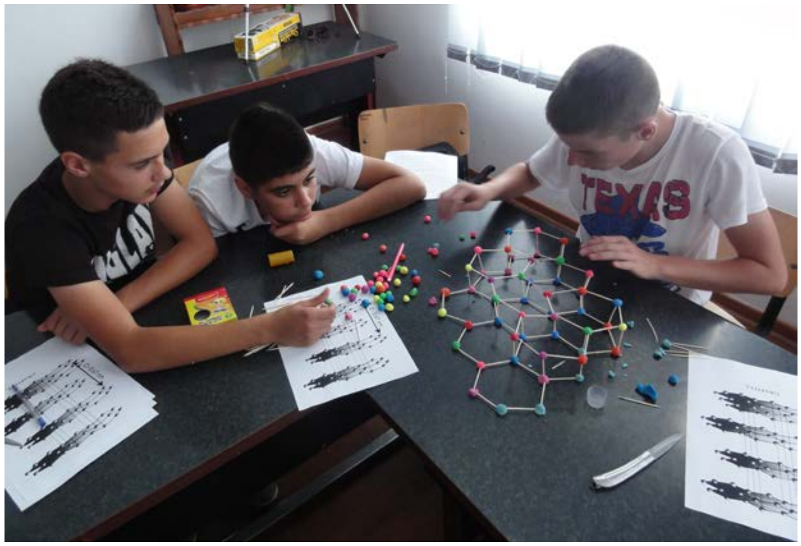
Web References (Links)

http://vlab.ntse-nanotech.eu/NanoVirtualLab/

http://ntse.ssai.valahia.ro/

http://htwins.net/scale2/
http://nanoyou.eu/en/nano-educators
http://www.nano.org.tr/tr/index.html
http://www.tryengineering.org
http://en.wikipedia.org/wiki/Fullerene
http://mrsec.wisc.edu/Edetc/cineplex/nanotube/index.html

IMAGES TAKEN DURING THE ACTIVITY




TEXAS
ENGLAND


NANOTECHNOLOGY