# Carbon allotropes: diamond and graphite

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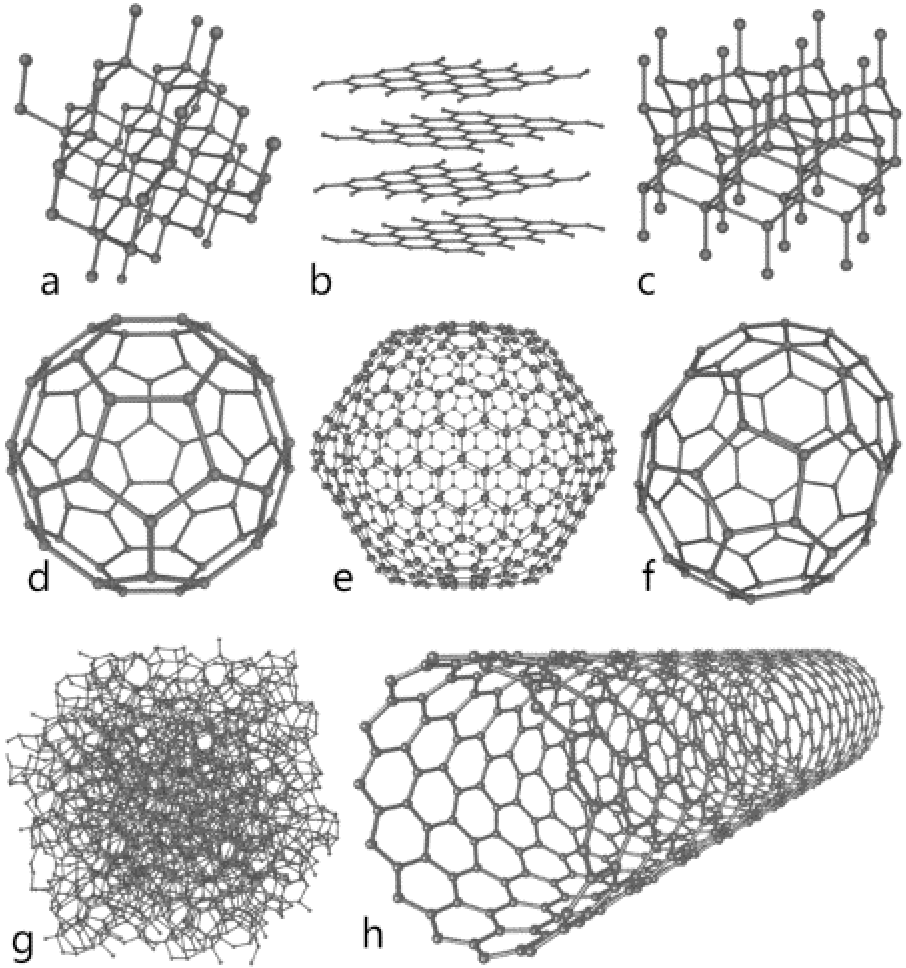
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# *The natural state*

Carbon is the fourth most common chemical element in the universe, and it is also the basic component of organic matter.

*From* $^{12}C$ *to*

# *In the free state*

Native carbon was known for many time in two allotropic forms: diamond and graphite.

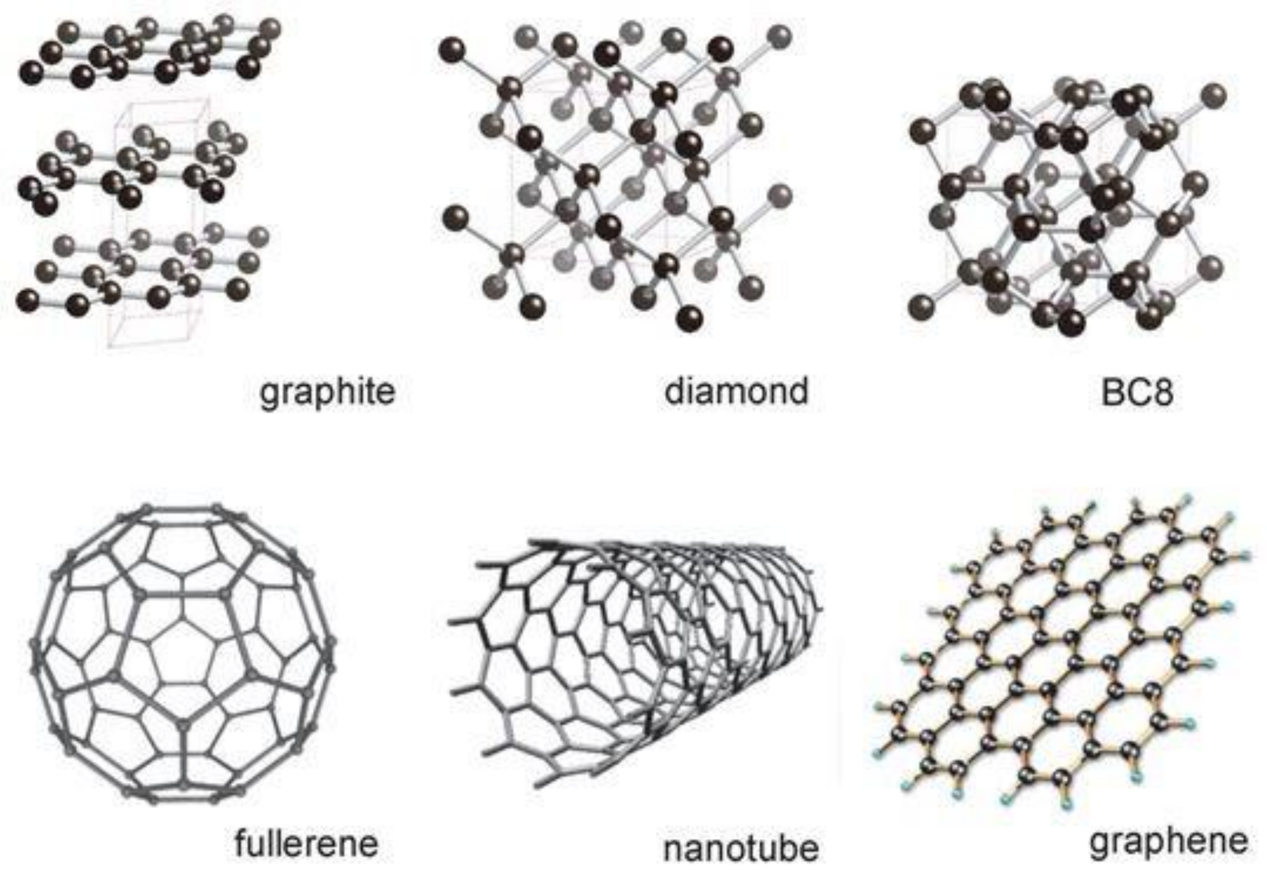
# *ALLOTROPY*

Today there are known several allotropes of carbon.

*From*

$^{12}C$

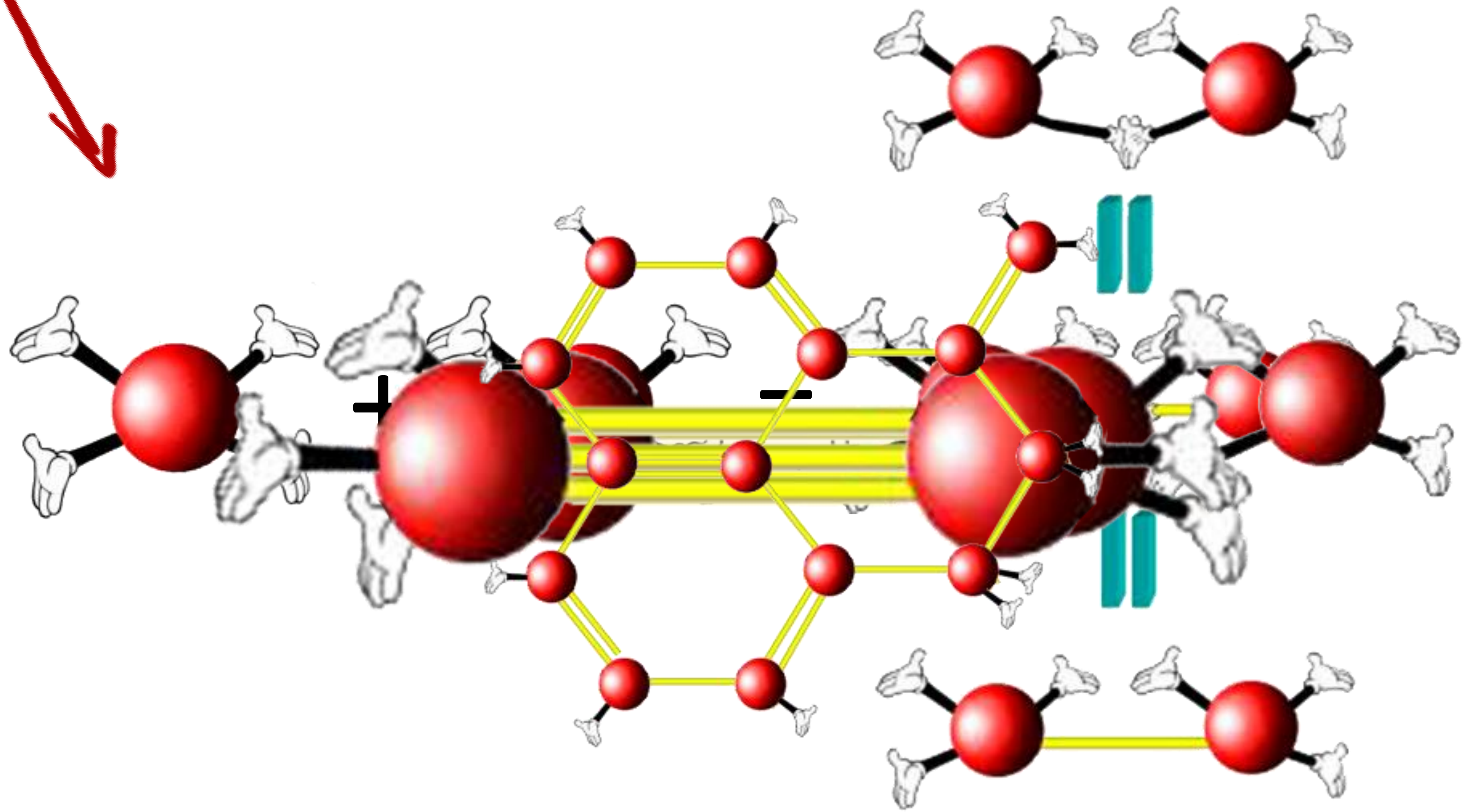
*to*



# Carbon

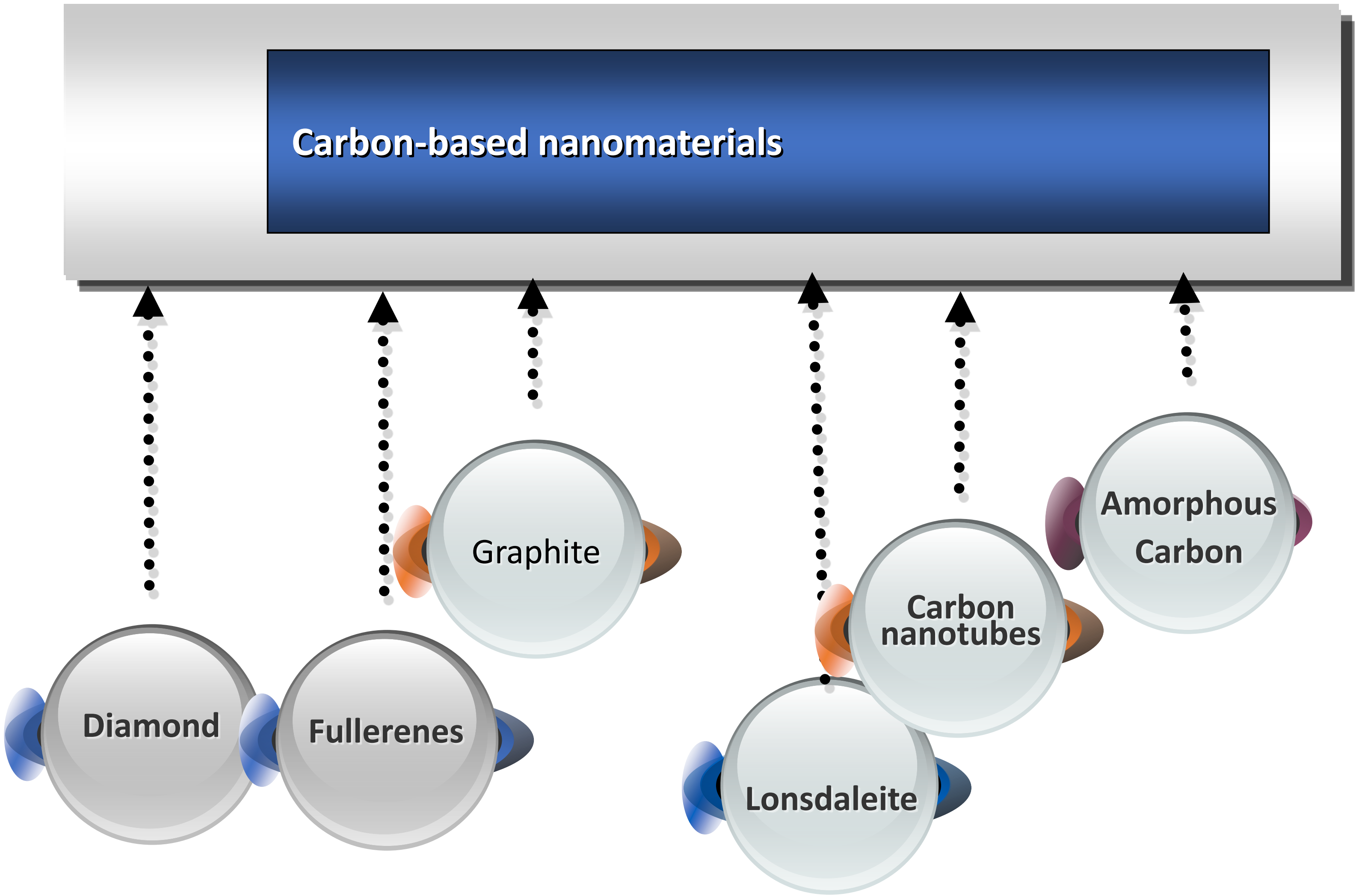
$^{12}C$

The carbon is a very unusual chemical element. Carbon atoms can associate between them or with atoms of other elements, leading to compounds with different properties. Between carbon atoms may exist simple, double, triple bonds.



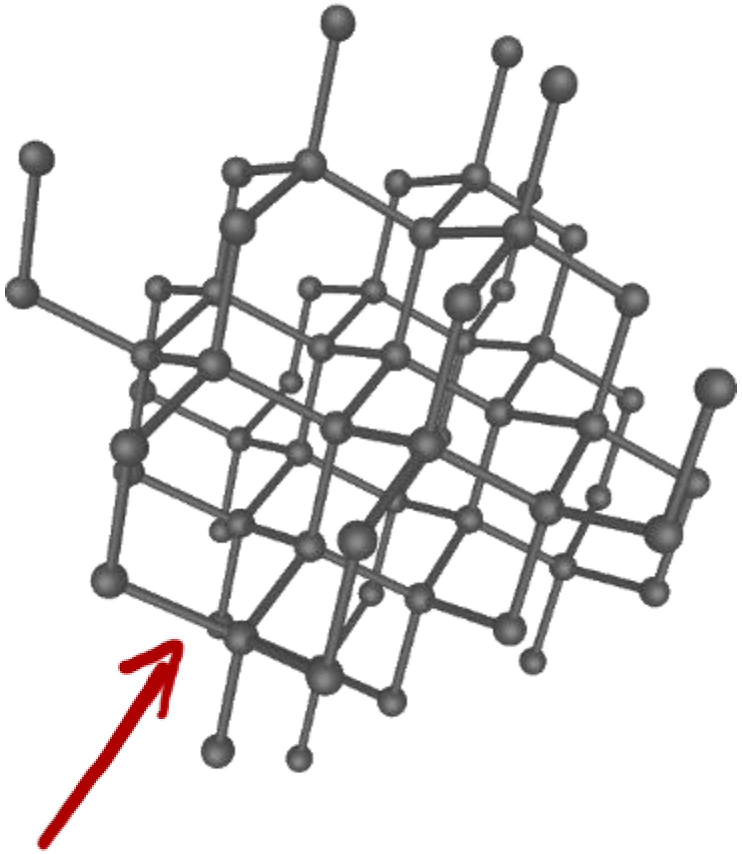
# What are carbon allotropic forms?

Possibility of different combination between carbon atoms leads to different allotropic forms of carbon.



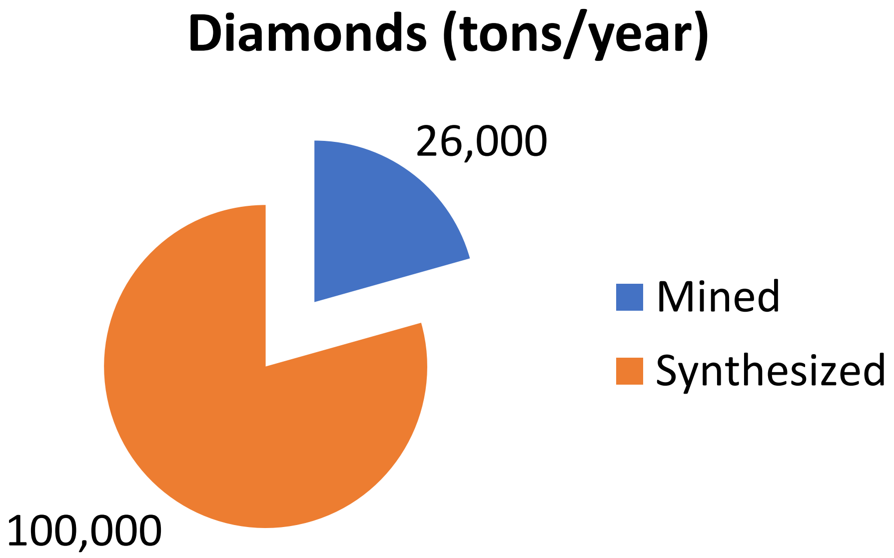

However, in the last century, science has given us a few more of its allotropic states: fullerenes and carbon nanotubes.

# Diamond

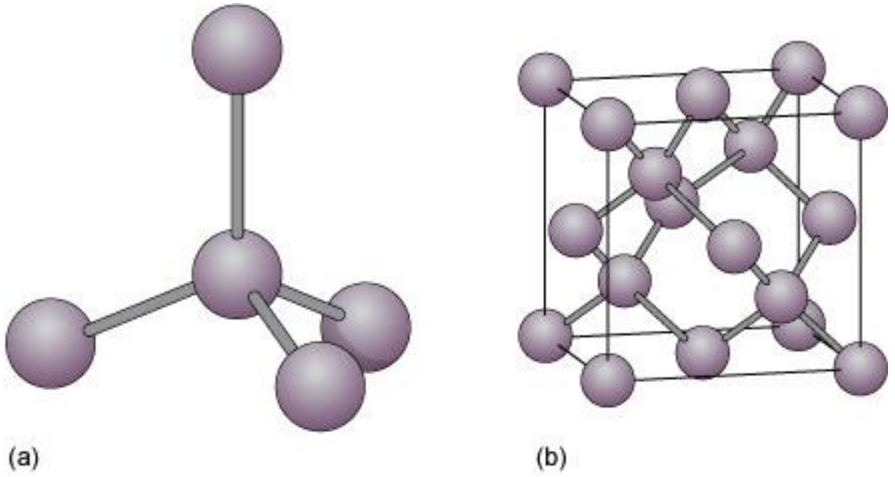


Structure of diamond

- (from the ancient **Greek** αδάμας – *adámas* "unbreakable"
- Appeared in human life 6000 years ago in India and its use was related to its beauty
- The hardest known natural material known on Earth



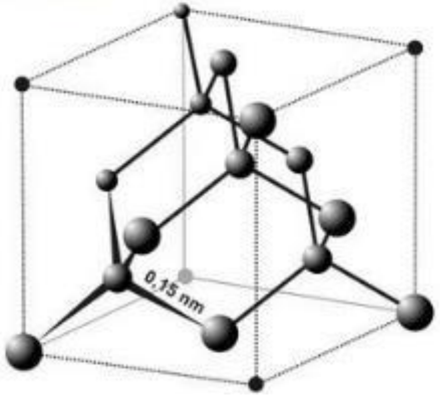
# Diamond




Structure of diamond

- In the diamond crystal, the atoms of the network are joined by covalent bonds.
- Each carbon atom in a diamond is covalently bonded to four other carbons in a tetrahedron.
- These tetrahedrons together form a three-dimensional network of six-membered carbon rings in the chair conformation, allowing for zero bond-angle strain.
- This stable network of covalent bonds and hexagonal rings is the reason that diamond is so incredibly strong as a substance.

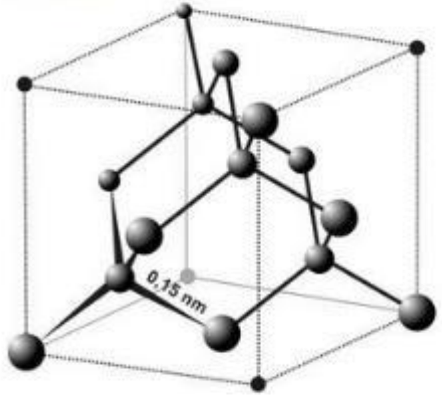
# Diamond




Structure of diamond

- As a result, diamond exhibits the highest hardness and thermal conductivity of any bulk material. In addition, its rigid lattice prevents contamination by many elements.
- The surface of diamond is lipophilic and hydrophobic, which means it cannot get wet by water but can be in oil.
- Diamonds do not generally react with any chemical reagents, including strong acids and bases.

# Diamond




Structure of diamond

## *Physical properties*

- solid colourless and transparent (various impurities can cause colouring), cubic crystallized;
- m.p. > + 350 ° C;
- harder than water;
- $\rho$ = 3.51 g/cm$^3$;
- insoluble in all dissolves;
- has the maximum hardness on the Mohs scale (10);
- electric insulator;
- reflects the light, being shining.

# Diamond

- The hardness and high dispersion of light of diamond make it useful for both industrial applications and jewellery.
- Diamond is **the hardest known natural mineral**. This makes it an excellent abrasive and makes it hold polish and luster extremely well.
- The **dominant industrial use** of diamond is in cutting, drilling, grinding and polishing.

Aspect of diamond

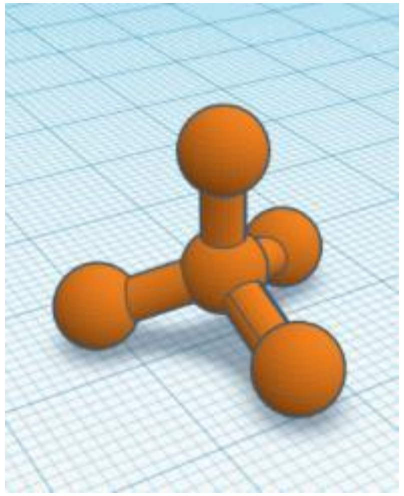



# Diamond

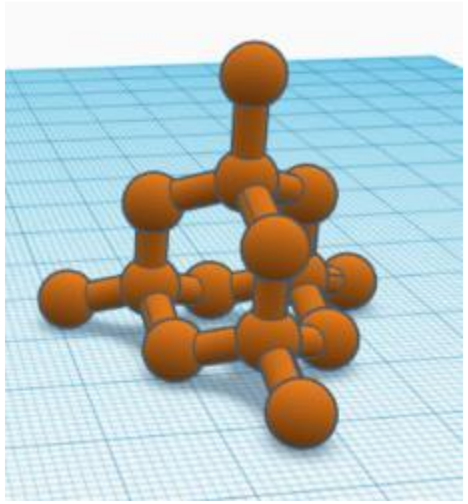
- Try to model for 3d printing the unit structure of the diamond, in respect with what you learn about the angles between the atoms and bond lengths it, till now.

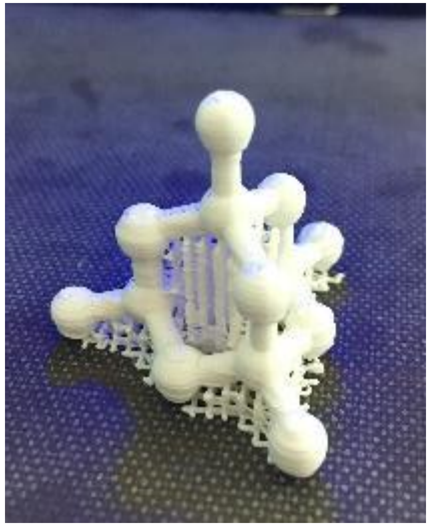
- Try to multiply the unit structure in 3d space, till you obtain 4 tetrahedrons.

- Print your model by using the 3d printer. You should obtain an object like this:



Structure unit of diamond

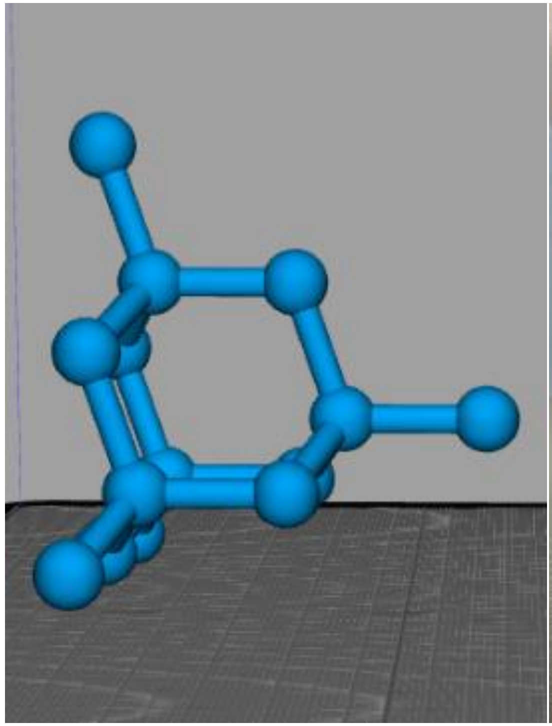


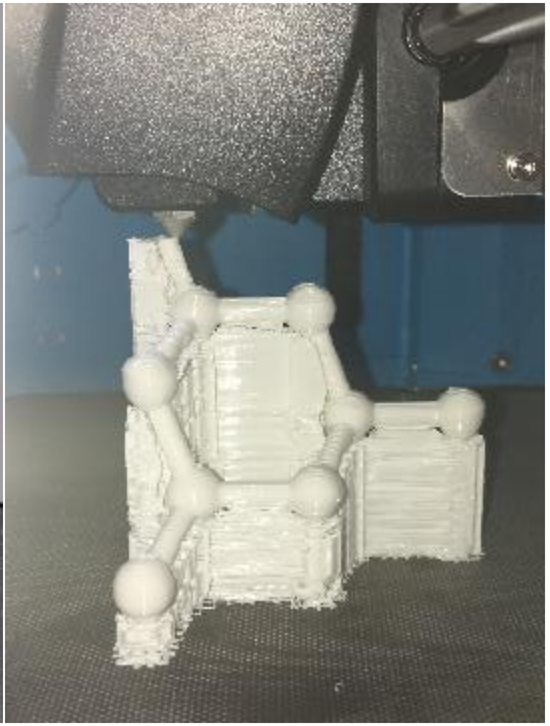


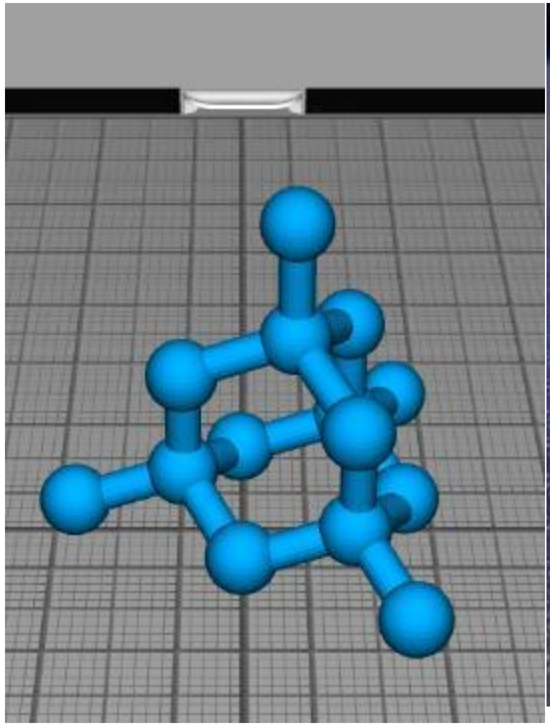
After printing, you should cut the unnecessary PLA wires, in order to polish the structure.

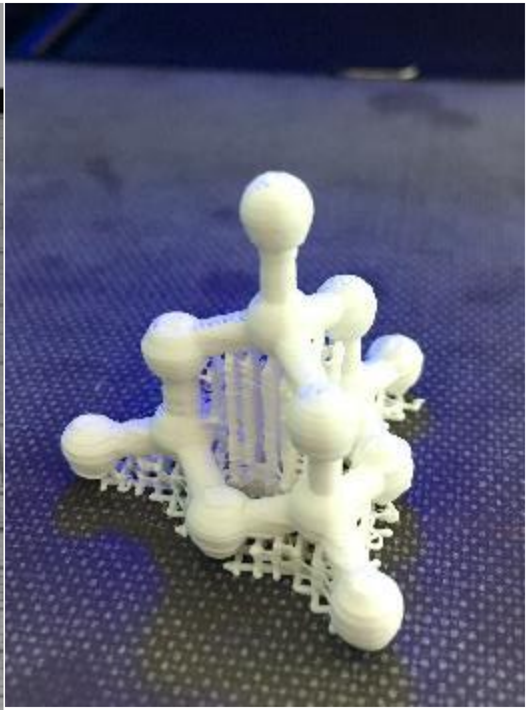
# Diamond

Obs.: Depending on the space position of the model in the printing area and on support pattern, more or less support material will be used.



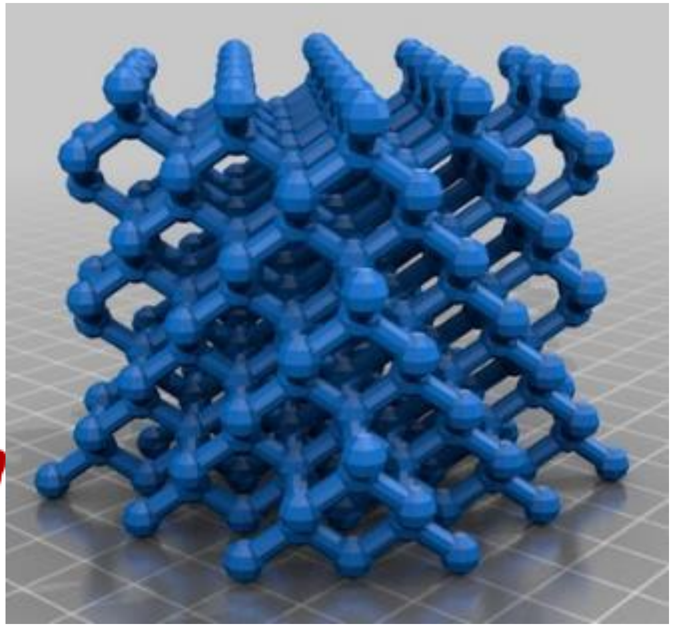






# Diamond

- If you continue to multiply and make the links between the tetrahedrons in space, you can even print the crystal structure of the diamond!



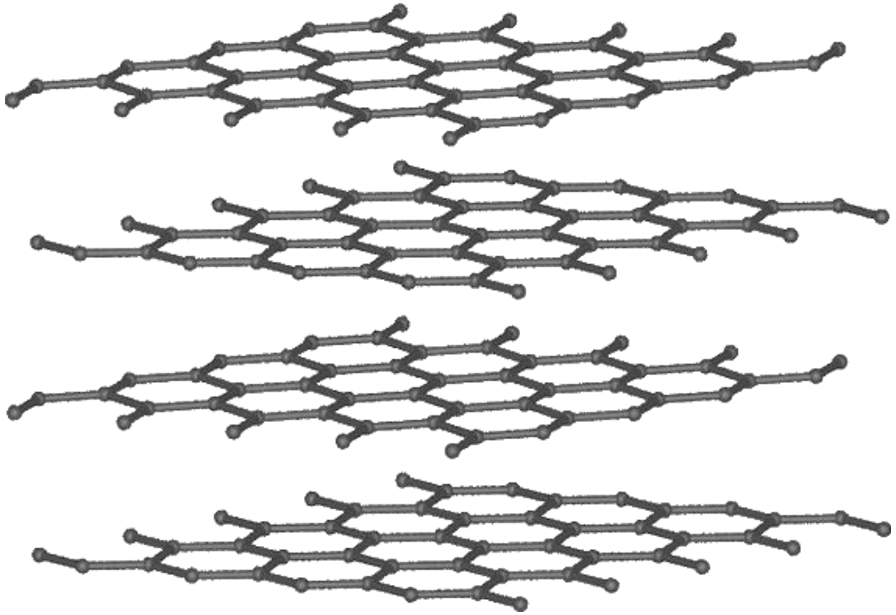
Structure of diamond crystal

- Analyse the structure printed! Can you explain yourself the rigidity and hardness of the diamond? Well Done!

# Graphite

Graphite is an other allotropic form of carbon, known for 6,000 years. Archaeological findings show that Eastern Europe was the first place where people have used graphite.

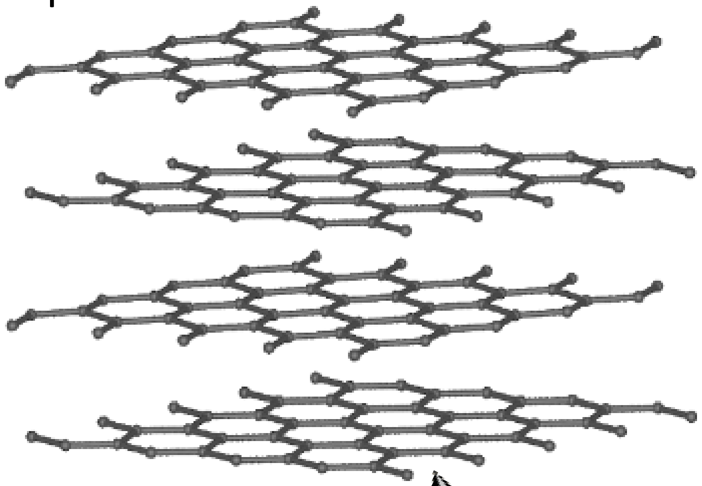
- from the Ancient Greek γράφω (*graphō*), ”to draw/write” for its use in pencils
- Iron-black to steel-gray; deep blue in transmitted light
- Graphite was used by the 4th millennium B.C. to create a ceramic paint in southeastern Europe

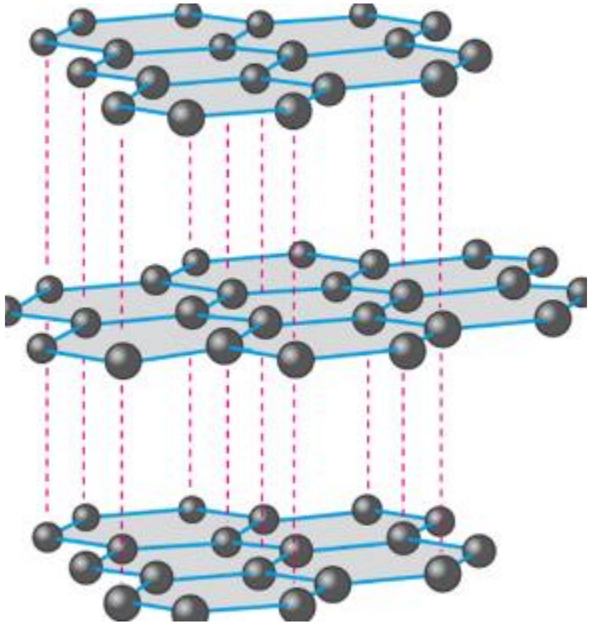


Structure of graphite

# Graphite

In graphite, each atom is joined by three other atoms by symmetrically oriented covalent bonds in the plane after the vertices of an equilateral triangle. Slow forces are established between successive plans.



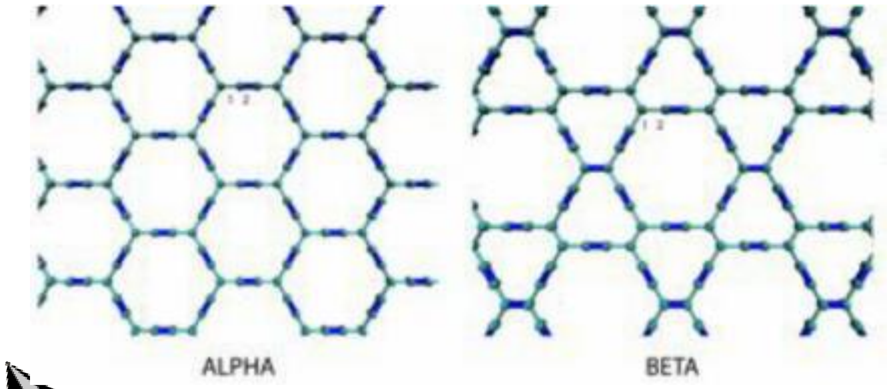


Structure of graphite

# Graphite

Graphite has a layered, planar structure. In each layer, the carbon atoms are arranged in a hexagonal lattice with separation of 0.142 nm, and the distance between planes (layers) is 0.335 nm. The two known forms of graphite, *alpha* (hexagonal) and *beta* (rhombohedral), have very similar physical properties (except that the layers stack slightly differently).

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.

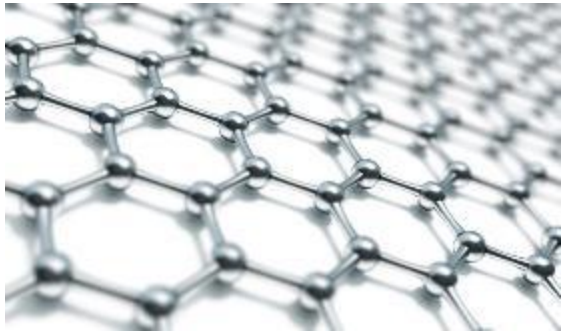


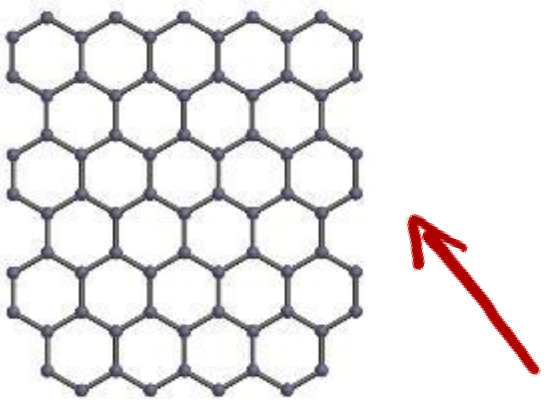

Structure of alpha and beta graphite

# Graphite

A single layer of graphite is called graphene. This material displays extraordinary electrical, thermal, and physical properties. It is an allotrope of carbon whose structure is a single planar sheet of $sp^2$ bonded carbon atoms that are densely packed in a honeycomb crystal lattice.

The carbon-carbon bond length in graphene is ~0.142 nm, and these sheets stack to form graphite with an interplanar spacing of 0.335 nm. Graphene is the basic structural element of carbon allotropes such as graphite, charcoal, carbon nanotubes, and fullerenes. Graphene is a semi-metal or zero-gap semiconductor, allowing it to display high electron mobility at room temperature. Graphene is an exciting new class of material whose unique properties make it the subject of ongoing research in many laboratories.



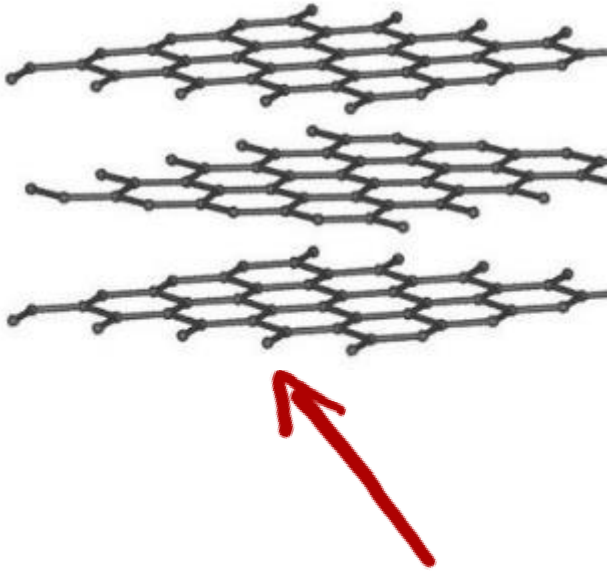


Structure of graphene

# Graphite

*Physical properties*

- solid opaque, black-gray, glossy, greasy, hexagonal crystallized;
- m.p. > + 350°C;
- harder than water, but lighter than diamond;
- $\rho = 2.25\ g/cm^3$;
- insoluble in all dissolves;
- low hardness (1 on the Mohs scale);
- electric conductor;
- Plans in which atoms are found slid over each other, leaving traces on the paper.



Structure of graphite

# Graphite

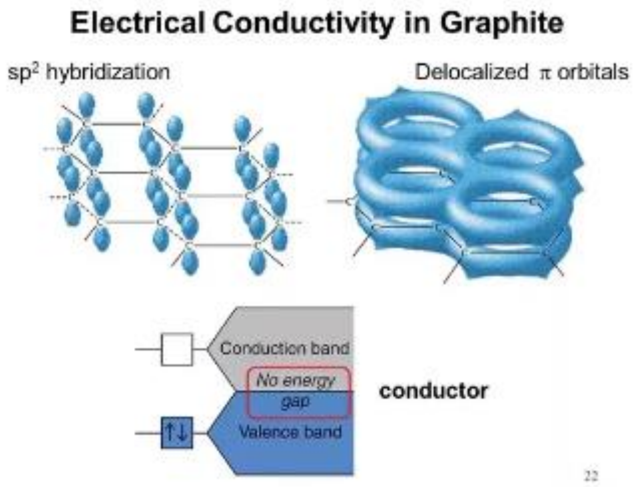
Graphite can conduct electricity due to the vast electron delocalization within the carbon layers; as the electrons are free to move, electricity moves through the plane of the layers.

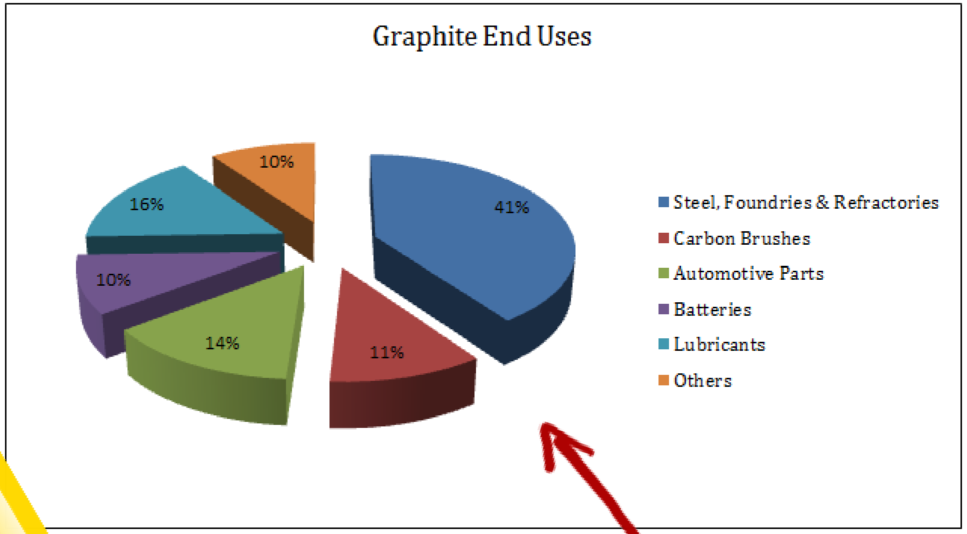
Graphite also has self-lubricating and dry lubricating properties.

Graphite has applications in prosthetic blood-containing materials and heat-resistant materials as it can resist temperatures up to 3000°C.

*Applications*

- pencil mines;
- metallurgical crucibles;
- electrodes;
- lubricants.

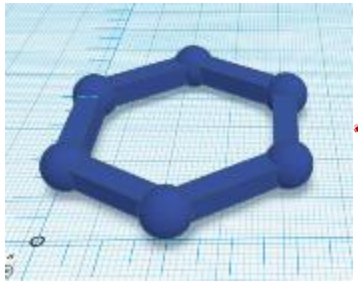


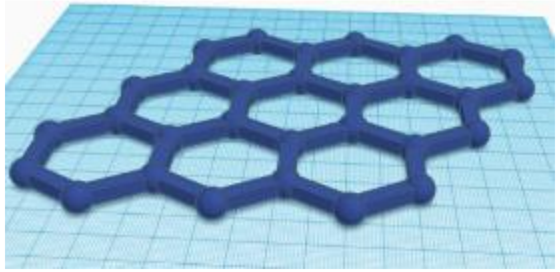

Graphite applications

# Graphite

- Starting from the hexagonal unit, try to model for 3d printing the unit structure of the graphene, in respect with what you learn about the angles between the atoms and bond lengths it till now.

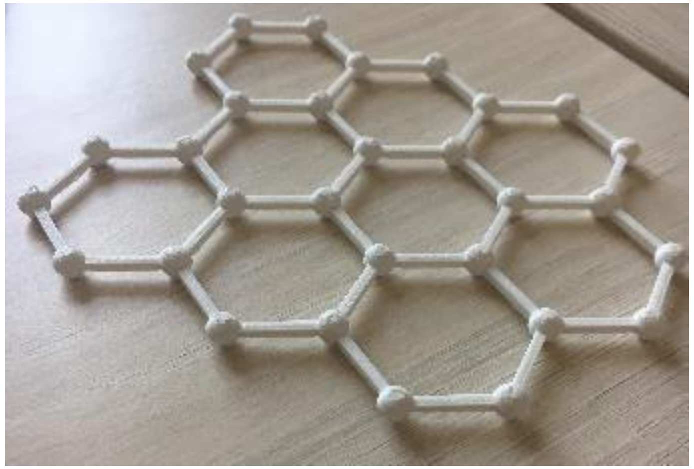


Hexagon unit



Structure of graphene

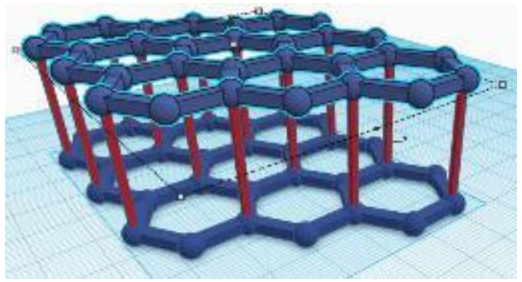
- Print your model of graphene by using the 3d printer. You should obtain an object like this:



- After printing, try to check the hardness/flexibility of the structure. Can you identify a difference between this structure and the diamond one?

# Graphite

- Based on the previous model, try to multiply the unit structure in order to obtain the planar structure of the graphite. Model a structure with at least two plans of carbon atoms.
- Print your model by using the 3d printer. You should obtain an object like this:

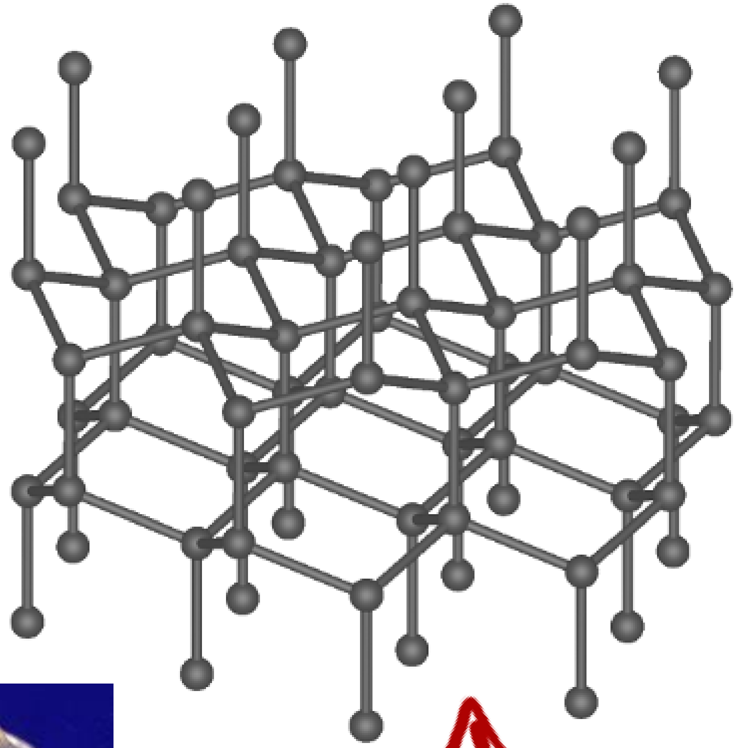


Structure of graphite

- After printing, you should cut the unnecessary PLA wires, in order to polish the structure.
- Try to see how the planes of carbon atoms are moving one to the other. This explains the cleavage of graphite.
- The free electrons that comes one from each carbon atom and moves between plans form a network that create the opacity of the graphite.

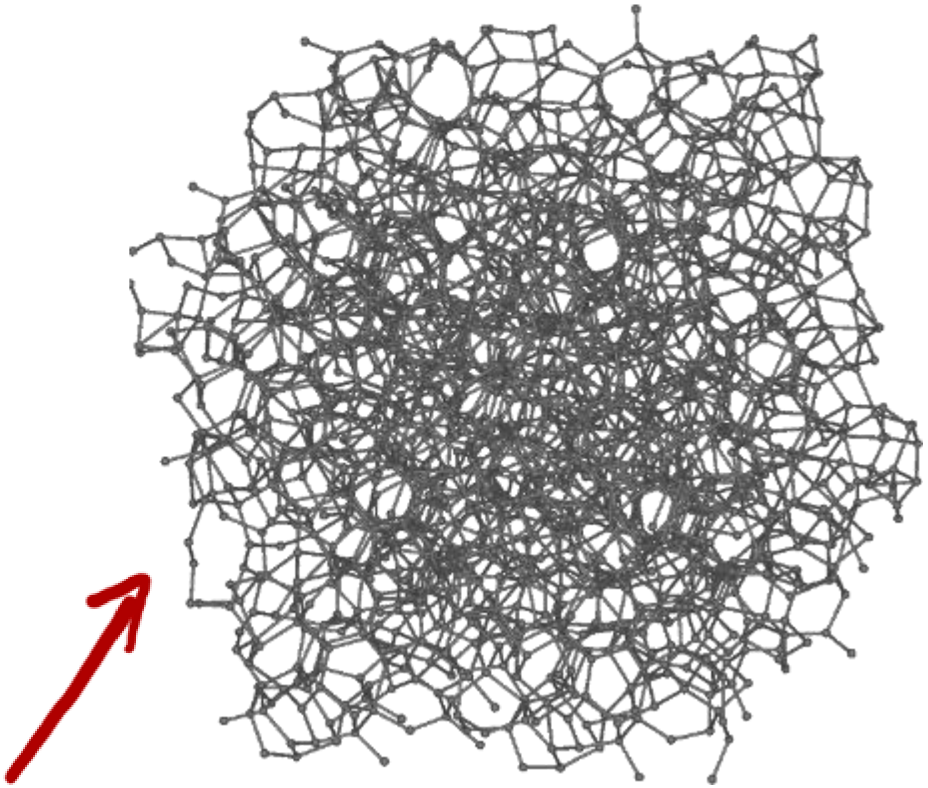
# Lonsdaleite

- Lonsdaleite is a very rare mineral, very similar to diamond
- named in honor of Kathleen Lonsdale, a British crystallographer
- Lonsdaleite was first identified in 1967 from the Canyon Diablo meteorite
- A simulated pure sample has been found to be 58% harder than diamond



Structure of **Lonsdaleite**

# Amorphous carbon



Structure of **Amorphous Carbon**

- ✓is free, reactive carbon that does not have any crystalline structure
- ✓In practice, generally, the many amorphous forms are chemical compounds with a high carbon content, and not pure allotropic form of carbon