Nano – materials

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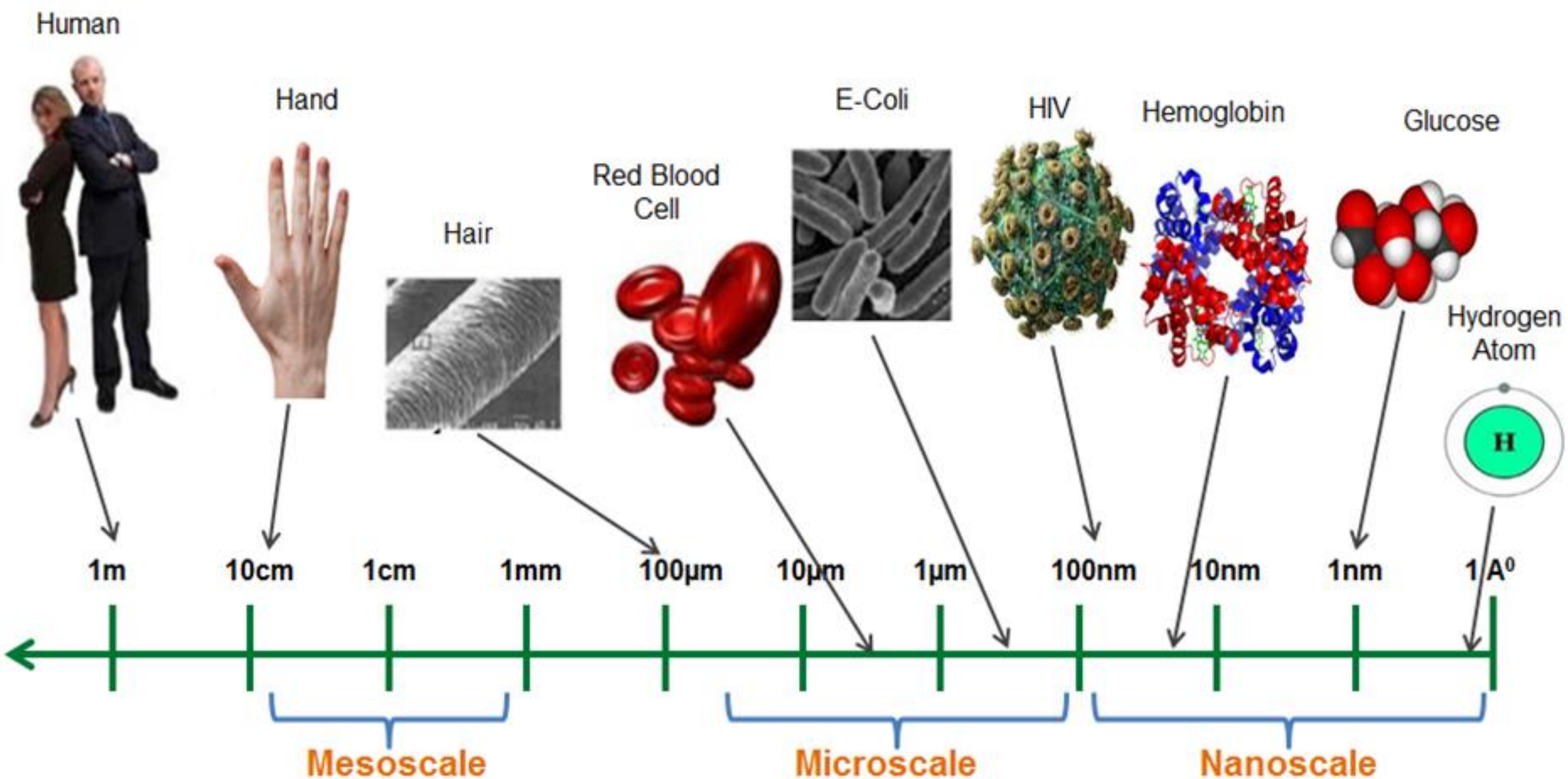
SZÉCHENYI ISTVÁN EGYETEM

Fizika és Kémia Tanszék

Scales



Human
Hand
Hair
Red Blood
Cell
E-Coli
HIV
Hemoglobin
Glucose
Hydrogen
Atom
H
1m
10cm
1cm
1mm
100µm
10µm
1µm
100nm
10nm
1nm
1 A⁰
Mesoscale
Microscale
Nanoscale

1. subsection

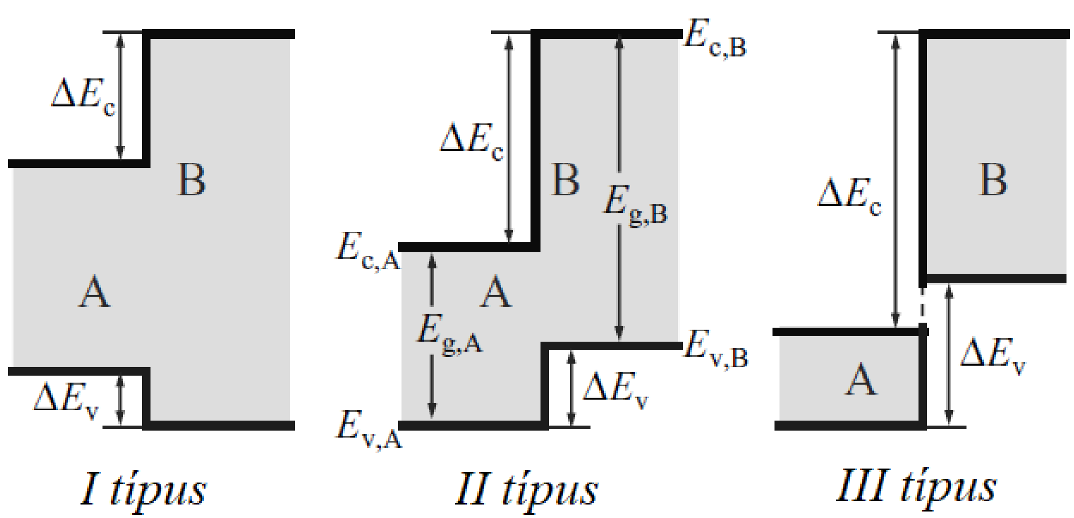
HETEROSTRUCTURES

Heterostructures

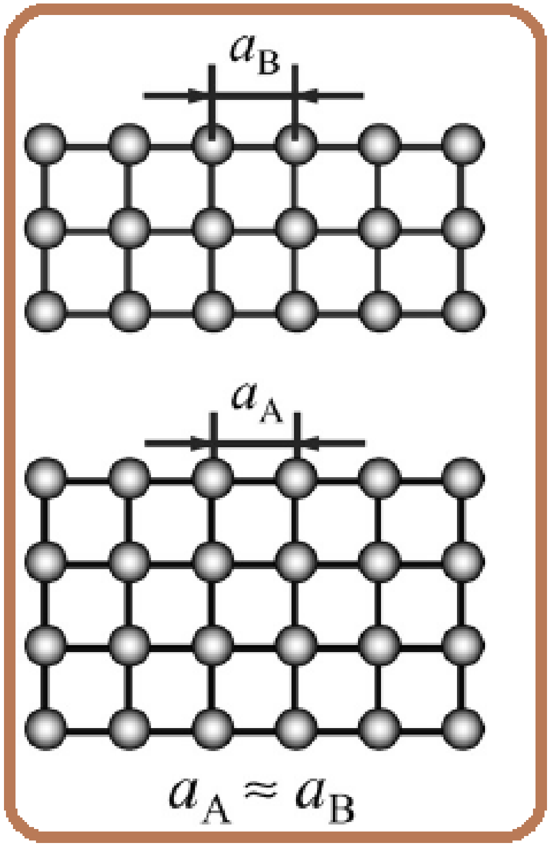
- In general, they are created by layer matching of surfaces consisting of different types of materials.
- Modern layer growth technologies make it possible to create bonding layers on atomic level.
- The quality of the matching layers greatly influences properties of the heterostructures.

Band fit

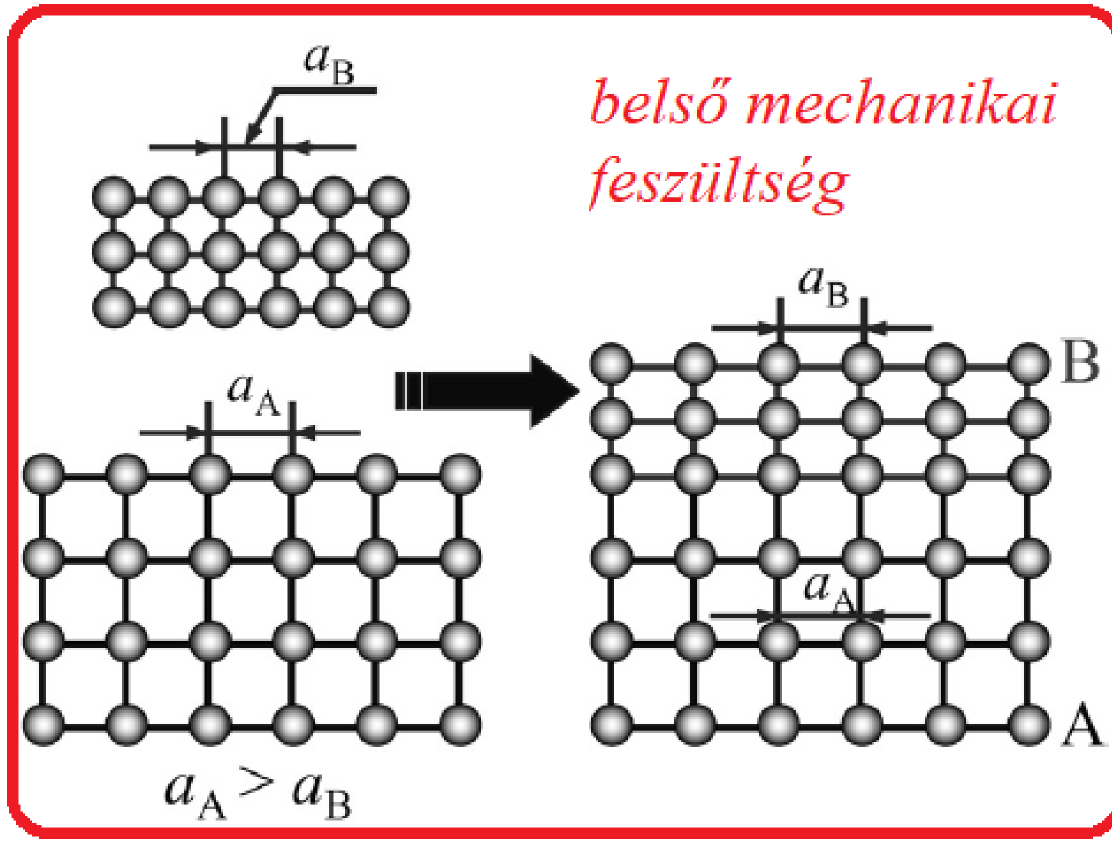
The relationship between the energy bands of different types of materials affects the behavior of electrons in heterostructures



Grid fit

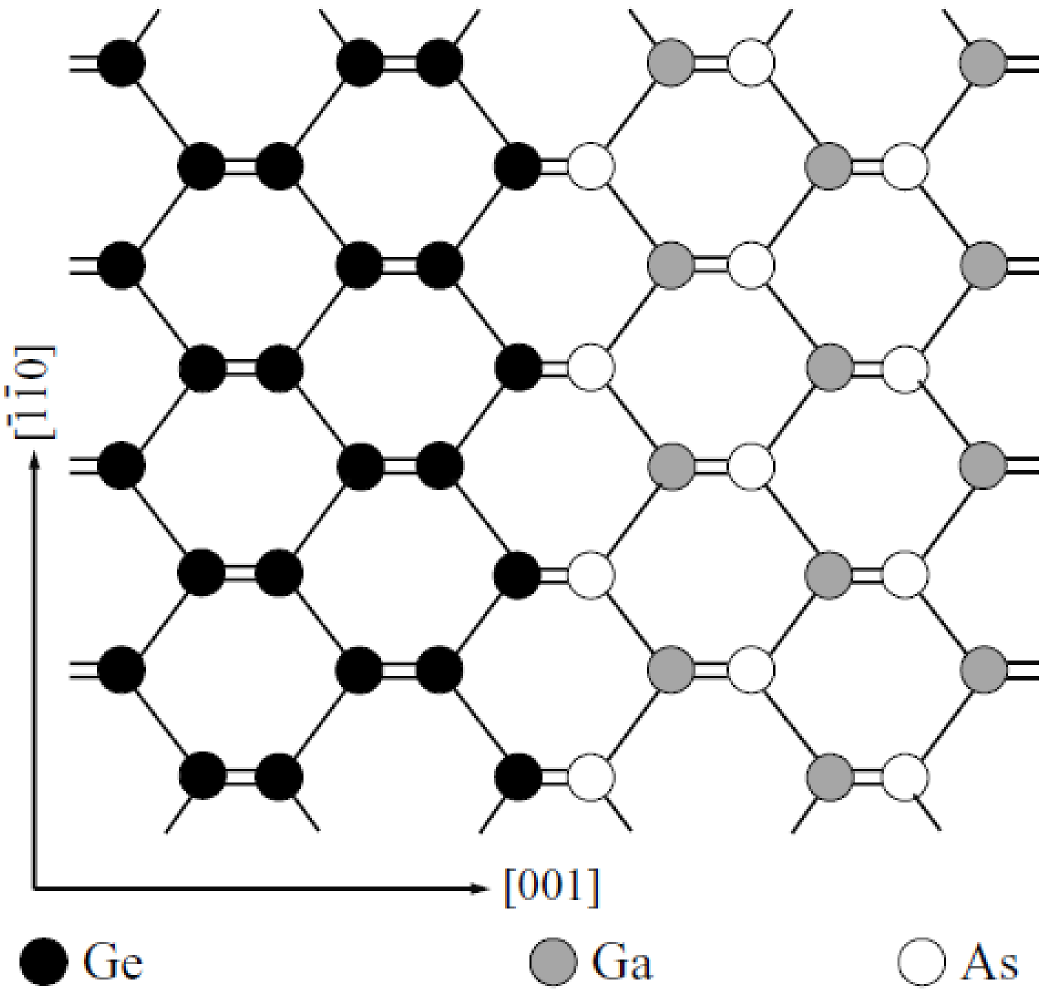


a_B
a_A
$a_A \approx a_B$



a_B
belső mechanikai feszültség
a_A
a_B
B
a_A
A
$a_A > a_B$

Valence matching



Ge – 4 binding e

As – 5 binding e

Ga – 3 binding e

As d acts as a donor in the heterostructure,

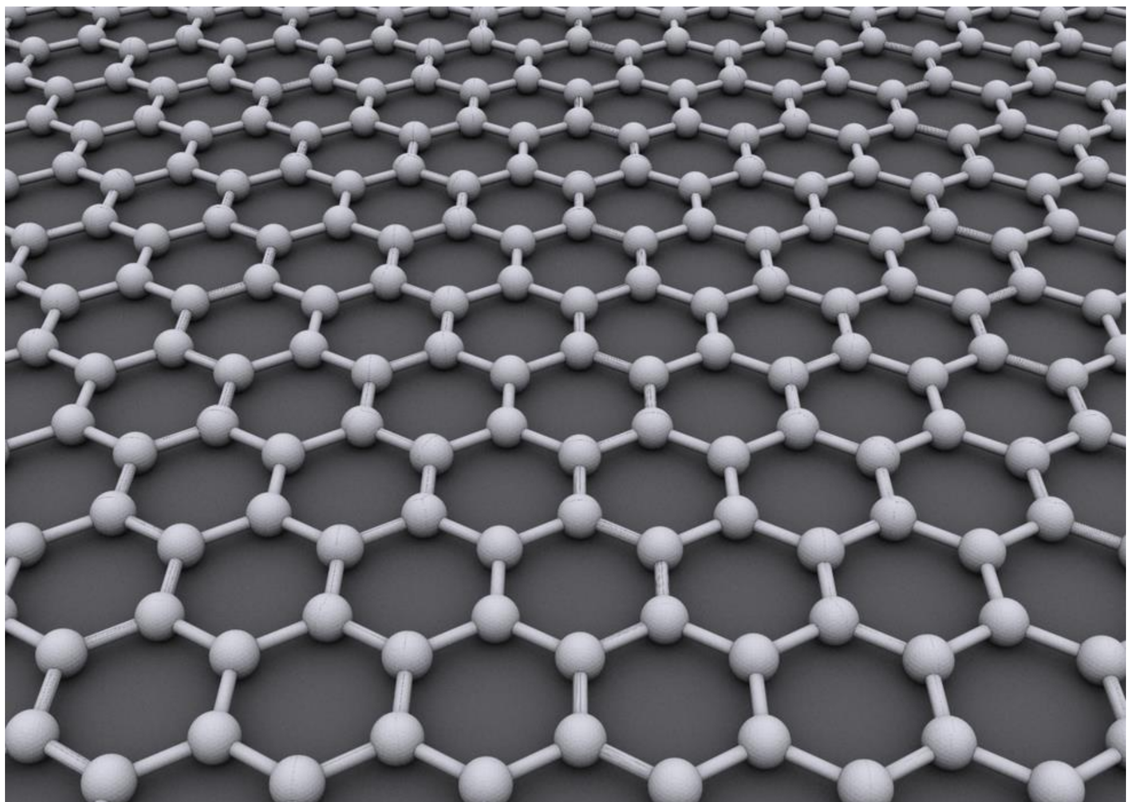
Ga acts as an acceptor in the heterostructure

2. subsection

GRAPHENE

Graphene

- A two-dimensional hexagonal lattice, each vertex of which is a carbon atom



Discovery

- The structure of graphite was theoretically predicted in the first half of the XX. century
- 1947: beginning of graphene theory – explanation of the electrical properties of graphite
- 1948: TEM images of a few layers of graphite
- From the 1970s: growing a few layers of graphite on various materials
- Andre Geim, Konstantin Novoselov: graphene layer separated from graphite - 2010 – Nobel Prize

Properties

- Thin (one atomic layer)
- Strong (200x stronger than the strongest steel)
- Good electrical conductor (better than copper)
- Good thermal conductor: (its thermal conductivity is 10 times of the copper)
- It is almost completely transparent

Structure

- 2D crystal lattice
- Hexagonal lattice
- Each atom has 4 bonds: 3 σ-bonds with neighboring atoms (responsible for stability) and 1 π-bond which is perpendicular to the plane
- σ-bond is stronger than π-bond
- Dictance of atoms: 1.42 Å (~0.14 nm)
- Its specialty: it transmits light almost completely, but it is so dense that even the smallest gas atom can't penetrate it

Chemical properties

- A single solid material with atoms capable of chemical reactions from both sides (2D)
- It is capable of a chemical reaction with oxygen above 260 °C
- Burns at 350 °C

Electrical properties

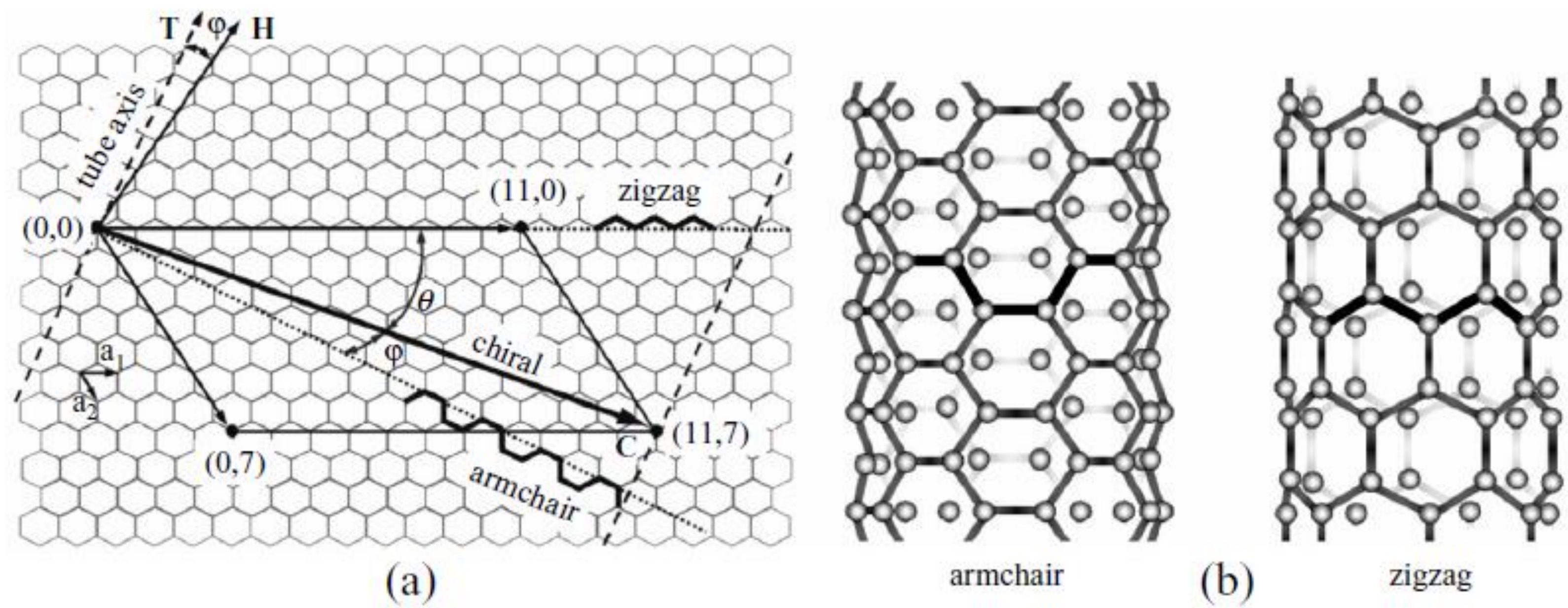
- graphene is a semiconductor
- the mobility of charge carriers is extremely high compared to classic semiconductors
- the electrical properties of materials are usually described by the Schrödinger equation – graphene is an exception
- the dynamics of charge carriers in graphene is described by the Dirac – equation
- the Dirac equation is consistent with both quantum mechanics and special relativity

Applications

- High light transmittance + good conductivity = touch screen
- Elektronics: FET – f > 100 GHz switching frequency
- Ultracapacitors
- Accumulators
- Sensors: pressure, magnetic field, Hall sensor
- Medicine

Carbon nano-tubes (CNT)

They can be made of graphene (two variants)



Ideal quantum wires!

3. subsection

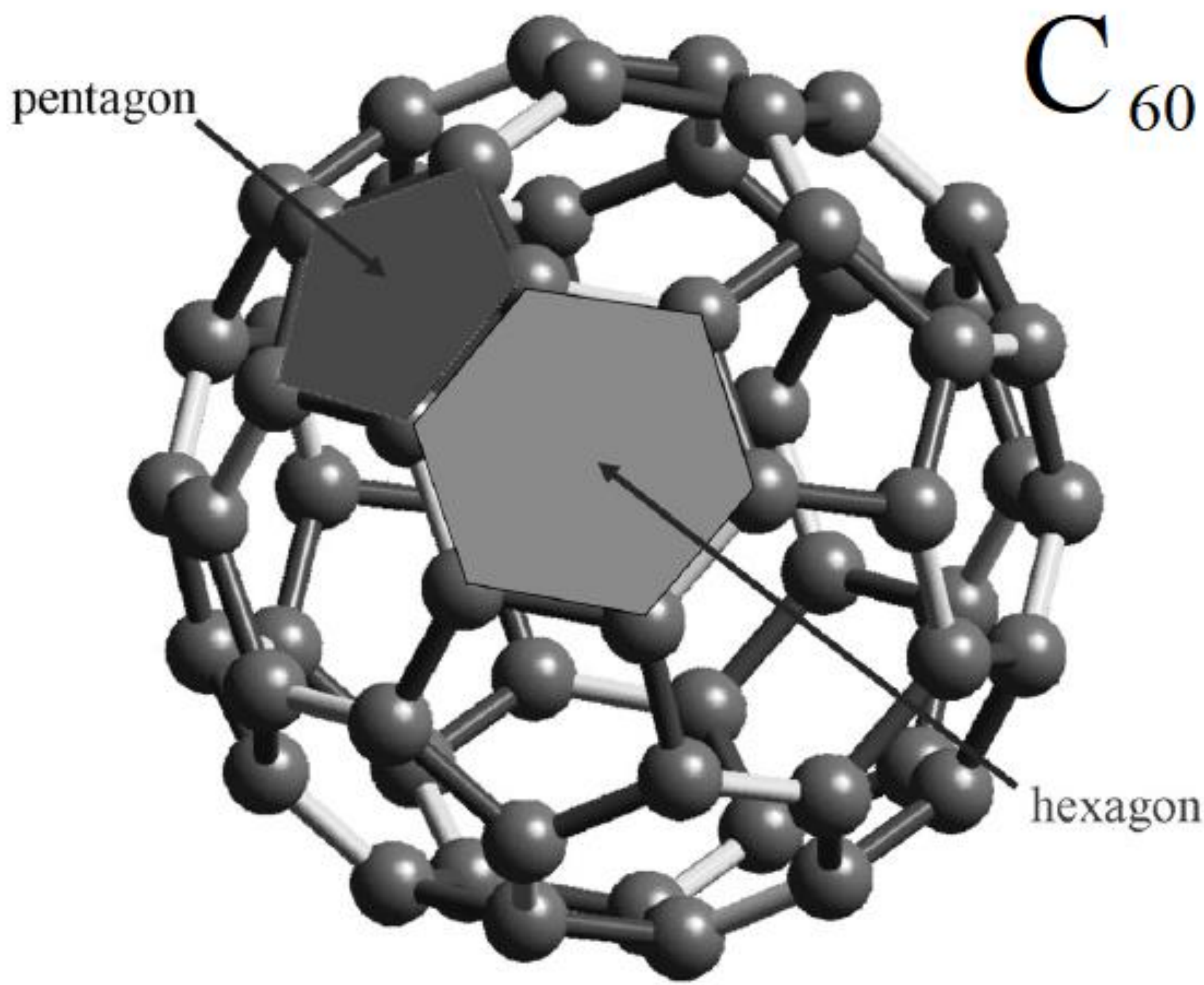
FULLERENS

Discovery

- Eiji Osawa (1970) – theory
- Harold Kroto, Robert Curl and Richard Smalley (1985) – experimental observation
- Nobel-prize in 1996

Structure

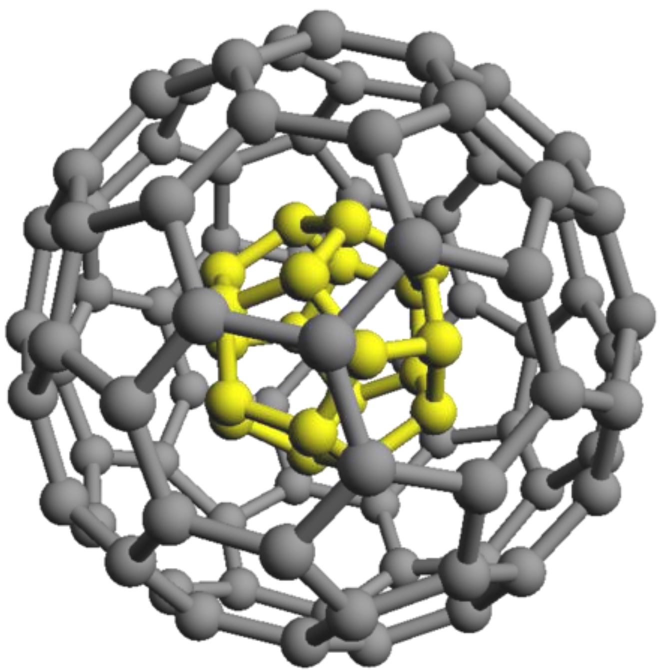
- Third allotropic modification of carbon.
- "Carbon molecules" consisting of a specific even number of carbon atoms (60, 72, 84, etc.).
- Each carbon atom is bonded to three other carbon atoms.
- One-to-double, two-to-one binding.
- The number of pentagons is always 12.

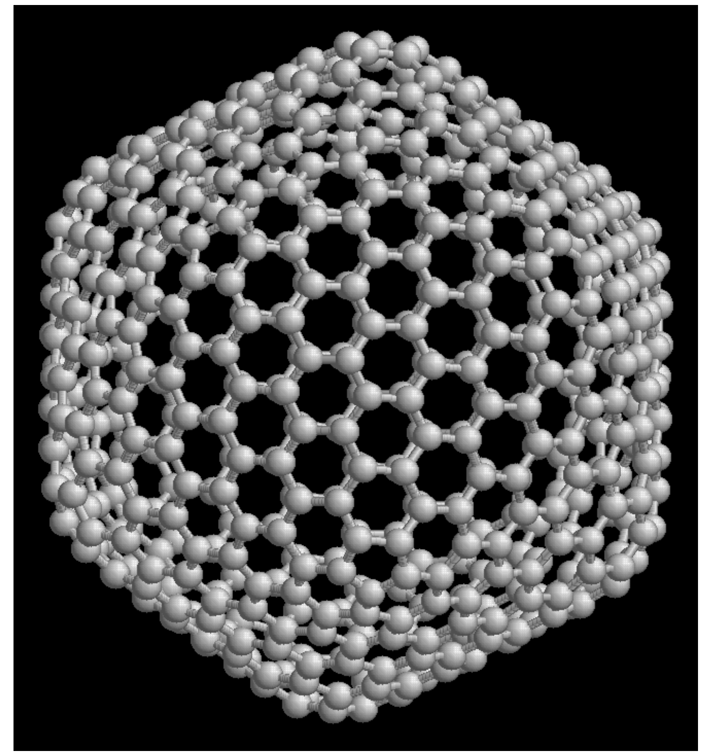

C 60
pentagon
hexagon

Variants

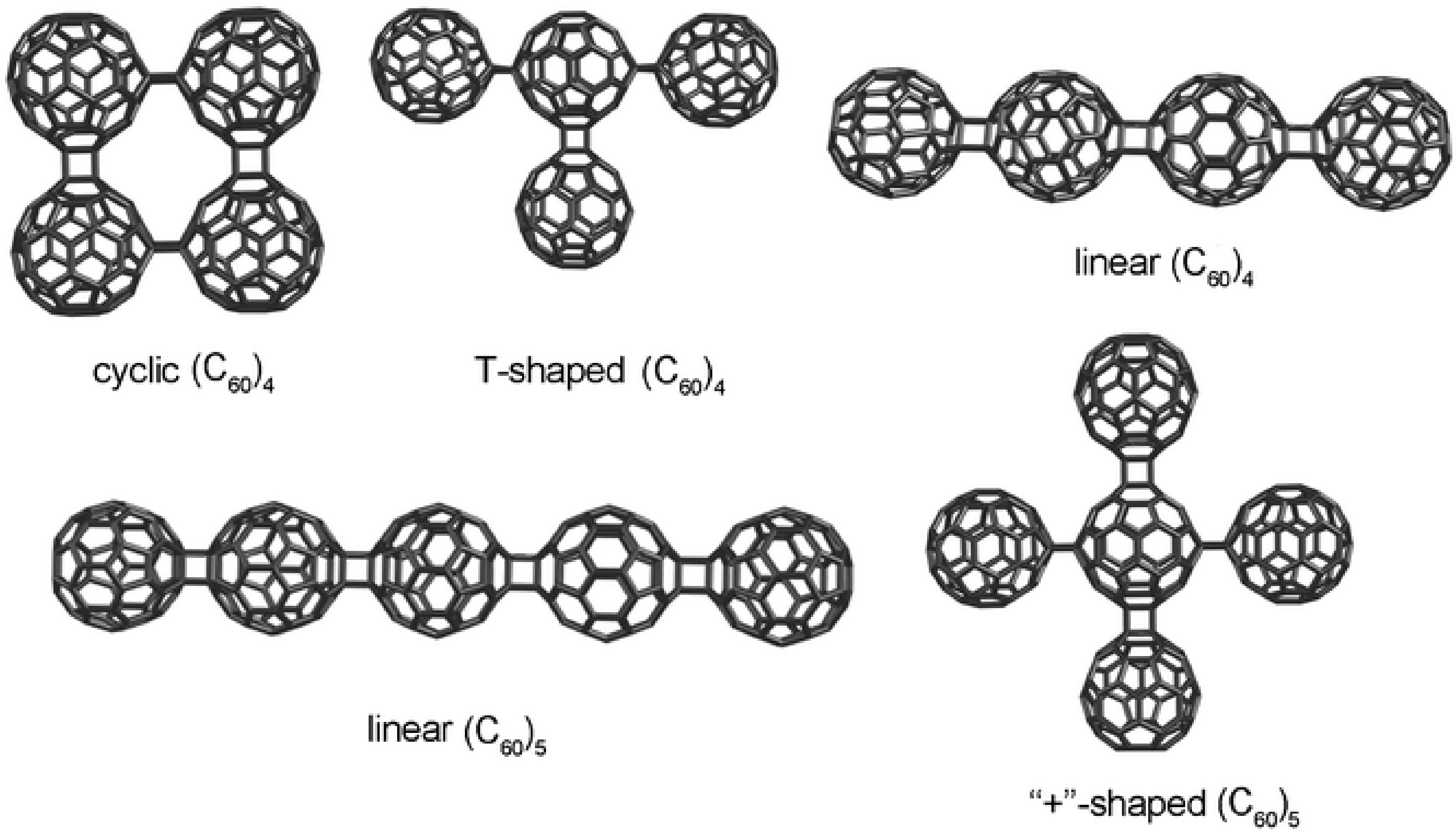
- Most frequent (C60, C70 C76, C78 és C84)
- The size of a fullerene can be increased indefinitely.
- Hyperfullerene consists of increasingly larger molecules in concentric spheres. C60 is surrounded by C240, then C540, C960 (can be continued indefinitely).

Hyperfullerens





Hyperfullerens



Properties

- Spherical structures
- Easily move on top of each other.
- They can be transformed into diamonds.
- Optical benefits
- Biologically active

Applications

- Lubricant
- Superconductor
- As an MRI contrast agent
- Application in a solar cell
- Thermal protection and flame retardant coatings

Summary

- Expensive
- Decreasing production costs
- High hopes