

## New Opportunities for the Development of Education at the Technical University of Liberec

Specific objective A2: Development in the field of distance learning, online learning and blended learning

**NPO\_TUL\_MSMT-16598/2022**



**KNT\_TNA\_Carbon nanomaterials**

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Funded by  
the European Union  
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**CZECH  
RECOVERY  
PLAN**

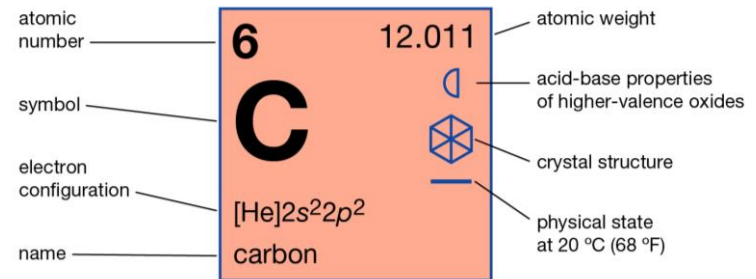
**MSMT**  
MINISTRY OF EDUCATION,  
YOUTH AND SPORTS

# Carbon

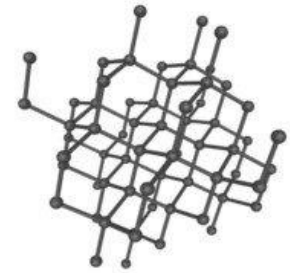
- Chemical element, the cornerstone of all living compounds

- Occurrence of carbon:

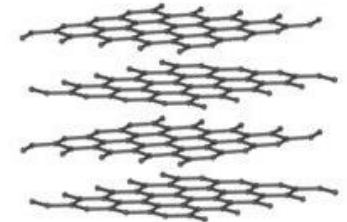
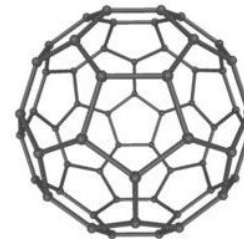
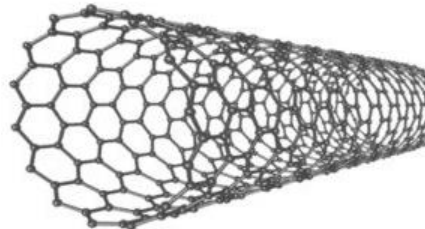
- Free carbon
- Organic compounds
- Inorganic compounds



# Forms of carbon

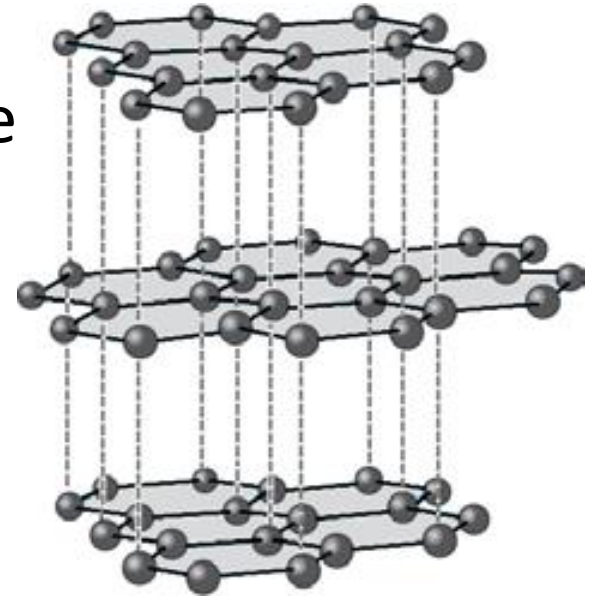


- Diamond - crystalline form of carbon
- Graphite - layers of graphene that hold together under the influence of van der Waals forces
- Graphene - carbons bound in hexagons
- Fullerenes - layers of five and hexagons, rolled into a "spherical" shape
- Nanotubes - cylindrically coiled graphene layers
- Nanofibers



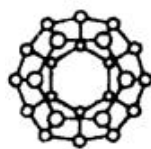
# Graphite

- The most common natural modifications of carbon
- It is composed of layers of graphene
- In the plane, atoms are connected by covalent bonds
- The individual layers hold together weak interactions - Van der Waals forces

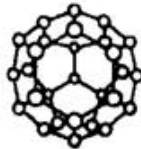


# Fullerenes

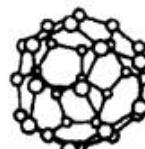
- Cyclic structures
- Composed of five and six membered rings of carbon atoms
- They most often take the shape of a sphere or ellipsoid



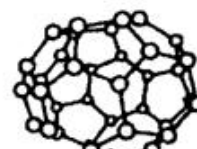
C<sub>24</sub>



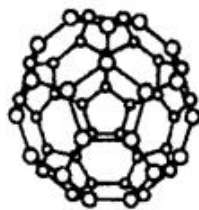
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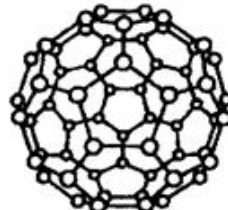
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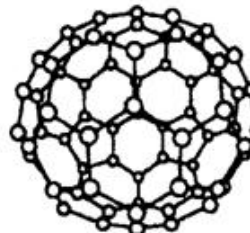
C<sub>36</sub>



C<sub>50</sub>



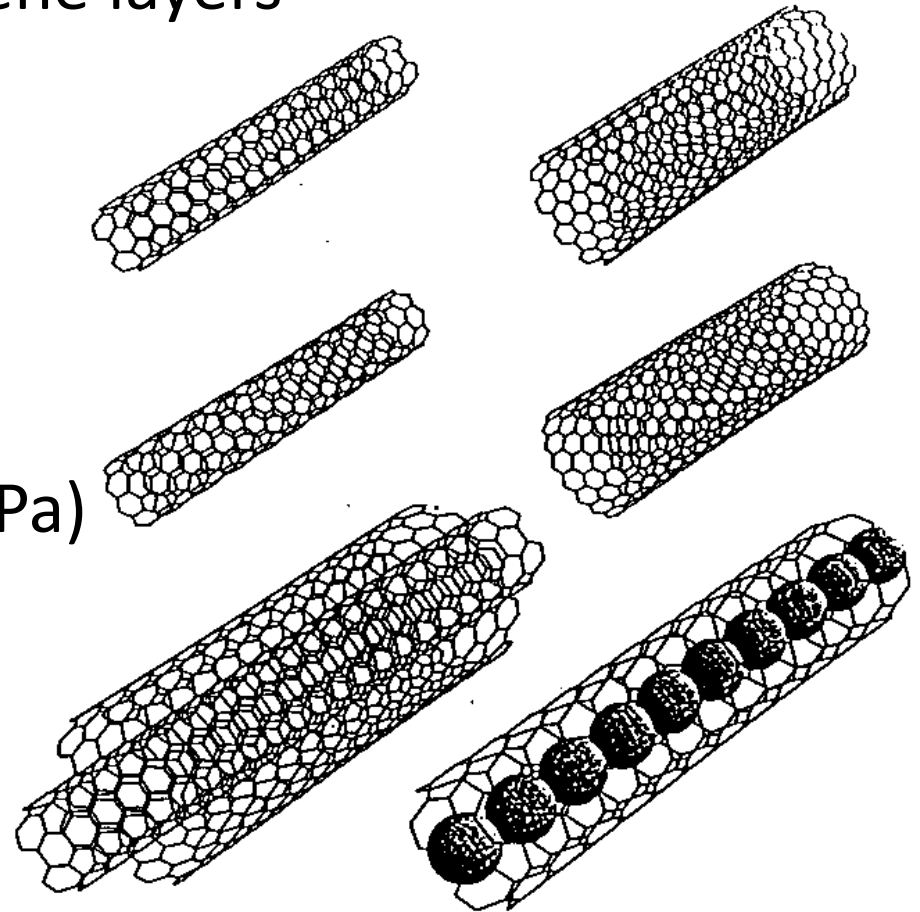
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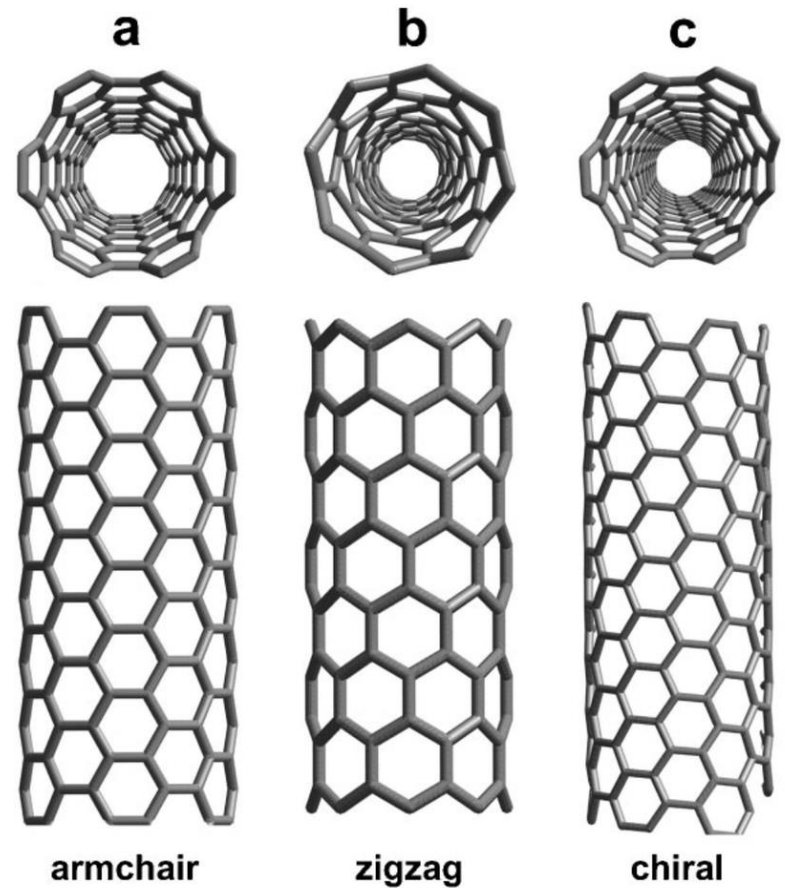
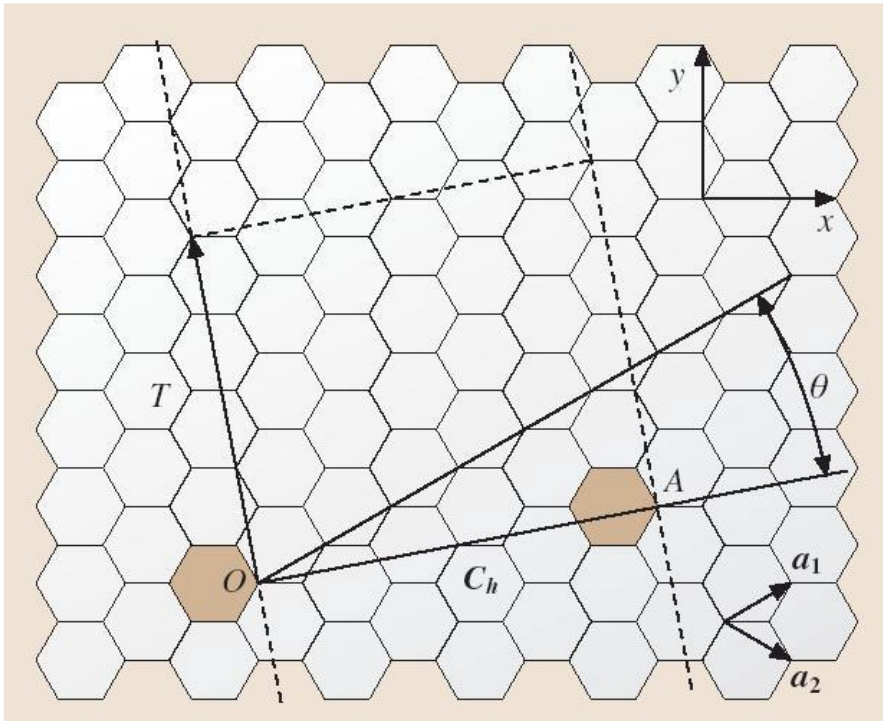
C<sub>70</sub>

# Nanotubes

- Cylindrical coiled graphene layers
- Diameter 0.5 - 100 nm
- Length up to 100  $\mu\text{m}$
- High strength (up to 1 TPa)



# Nanotubes - structure



# Nanotubes - arrangement

- SWCNT – Single wall carbon nanotubes
- MWCNT – Multi wall carbon nanotubes

SWCNT



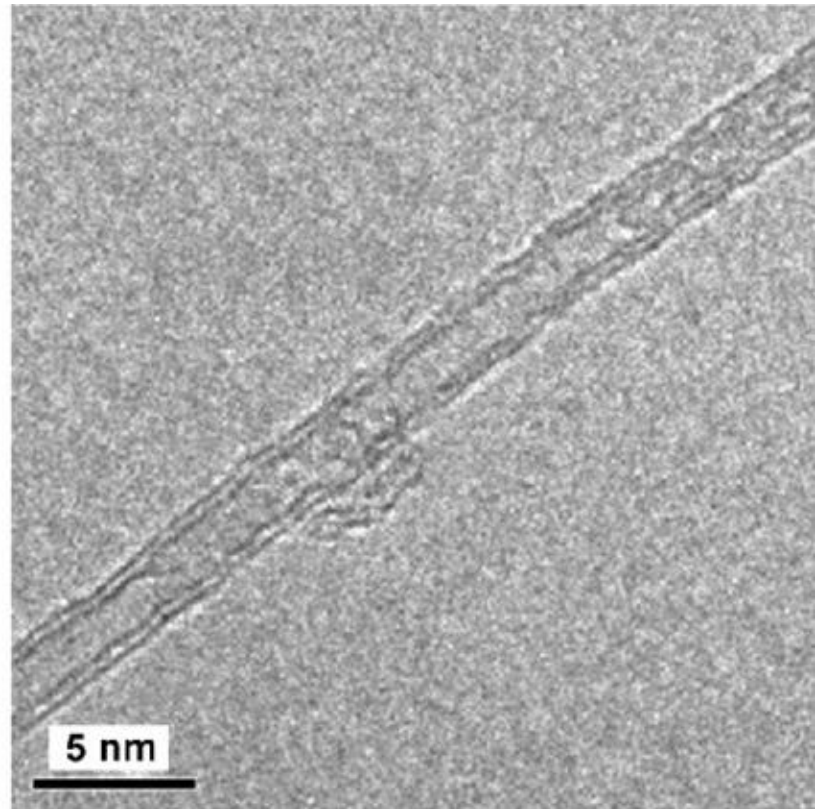
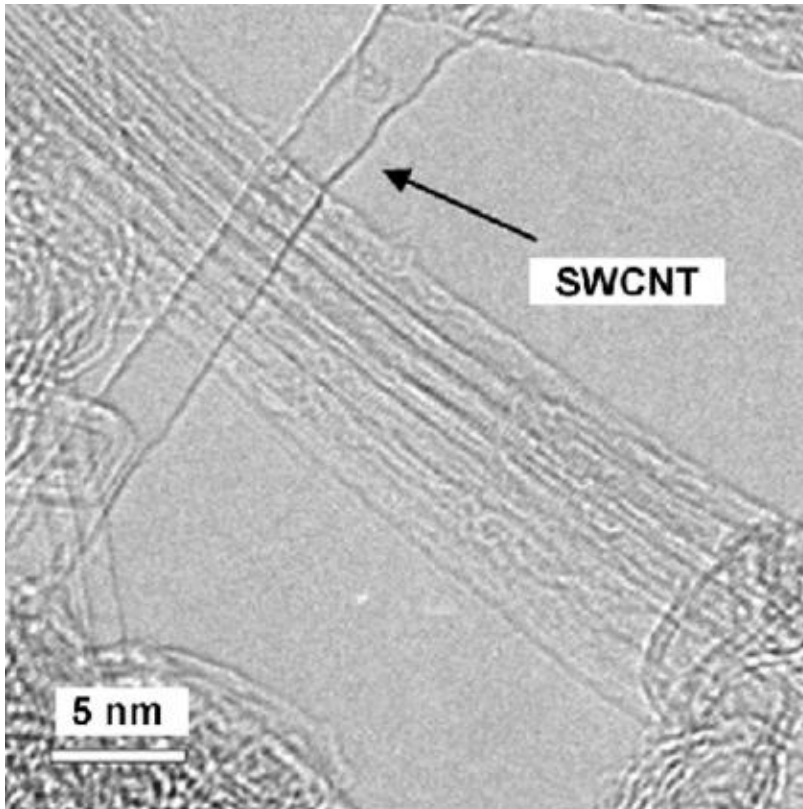
MWCNT





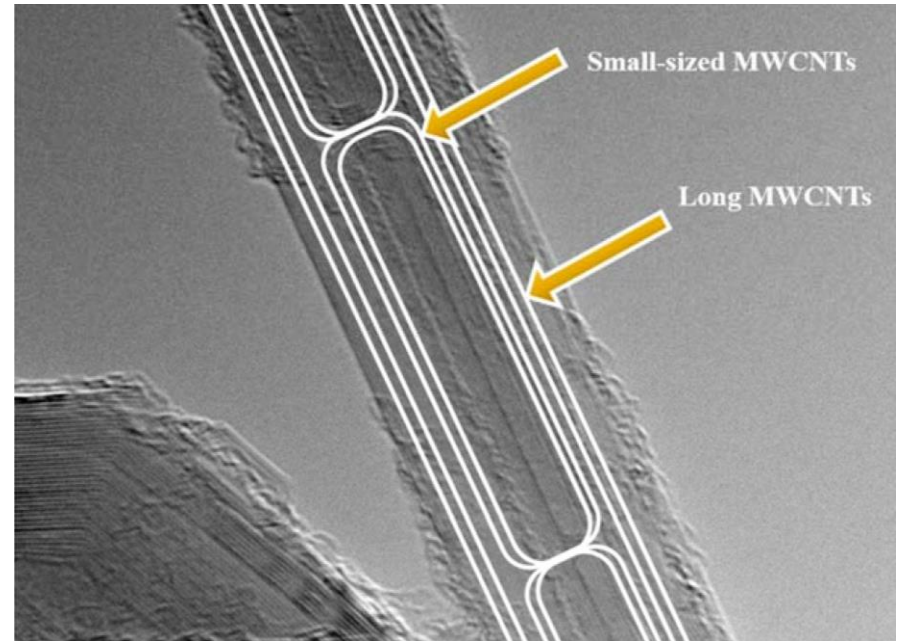
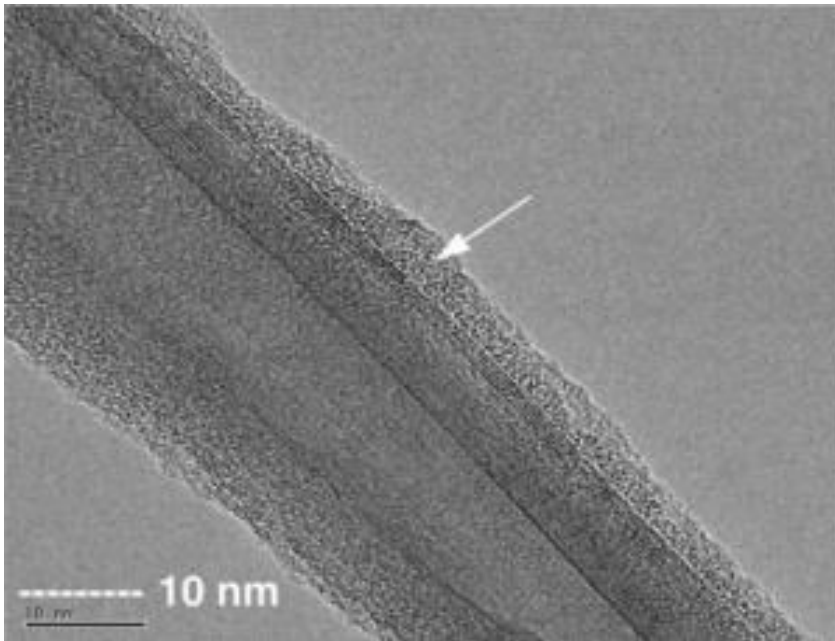
# SWCNT

- It contains one layer of graphene
- Diameter 0.5 - 2 nm



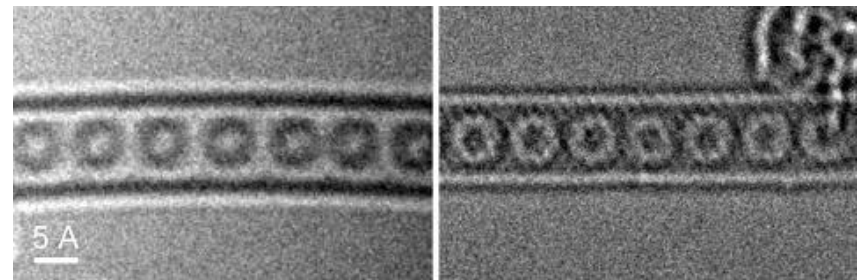
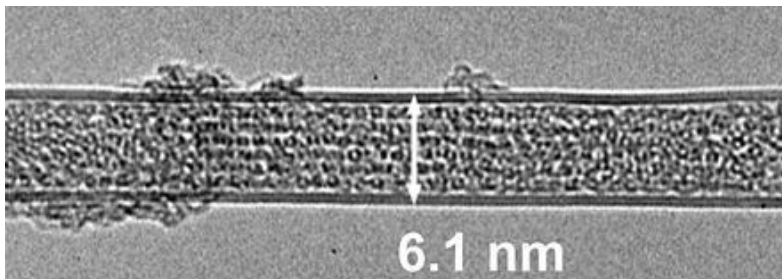
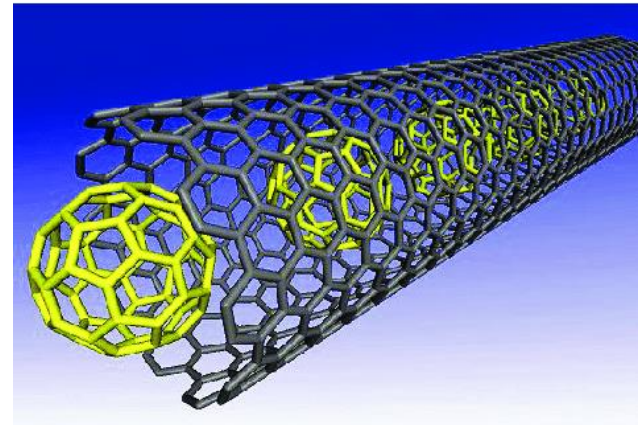
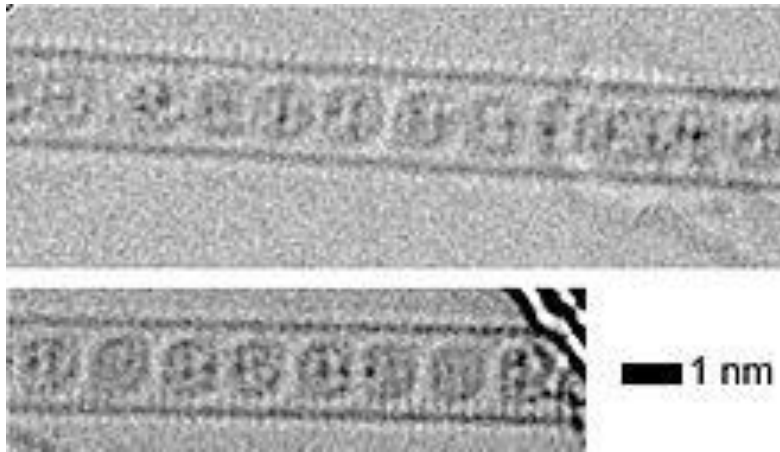
# MWCNT

- They consist of several single-walled graphene tubes
- Diameter 5 - 100 nm



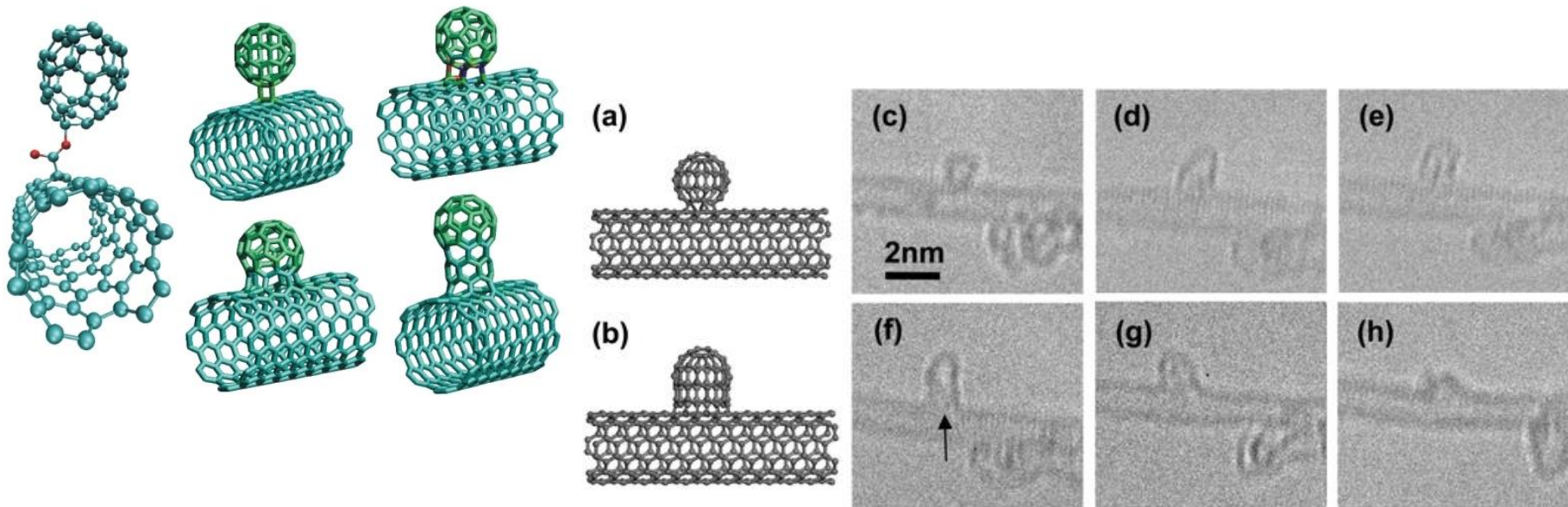
# Modification - Peapods

- The nanotube is filled with fullerenes



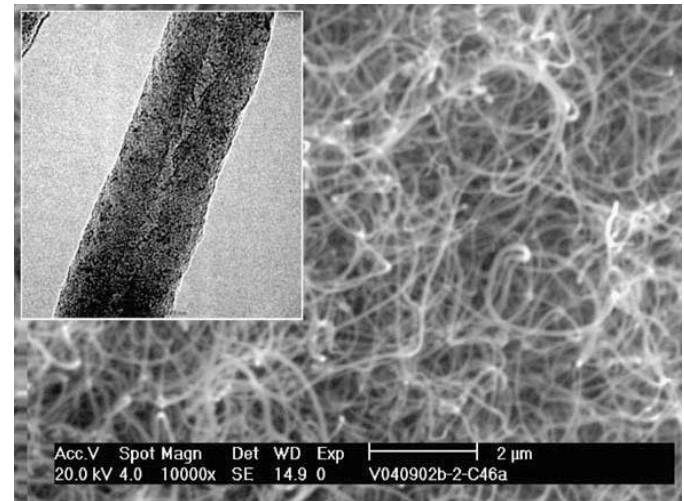
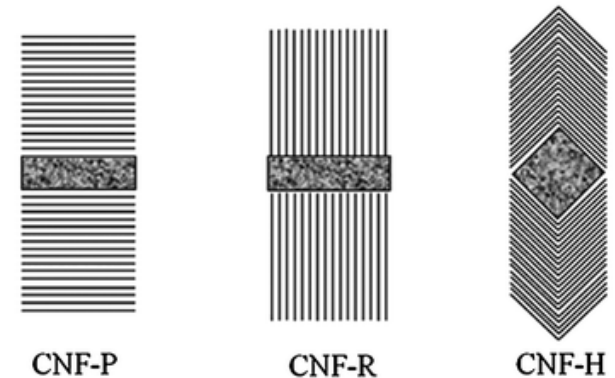
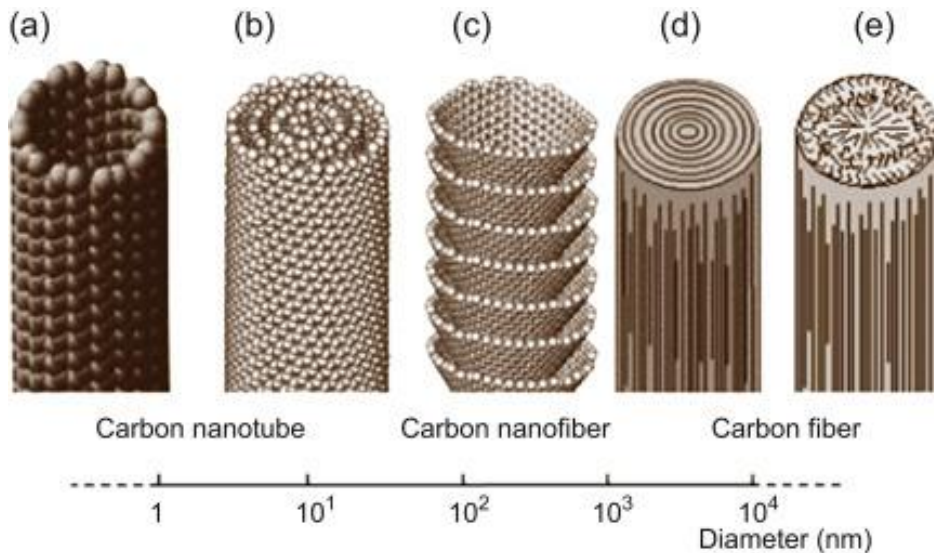
# Modification - Nanobuds

- Combination of nanotubes with fullerenes
- Fullerenes are attached to a nanotube



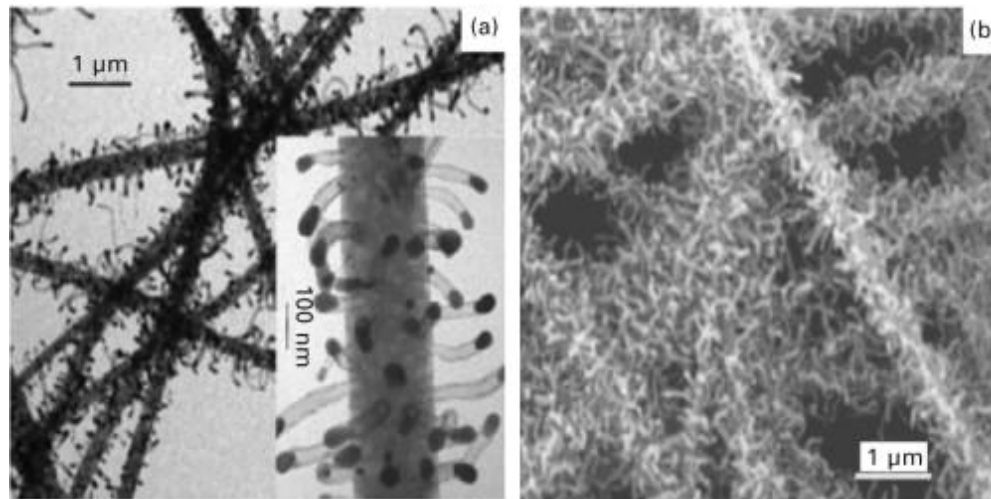
# Carbon nanofibers

- Fibers are formed by arranging layers of graphene in plates, strips, or "fish bones"
- Fiber diameter 100 - 200 nm
- Fiber length 50 - 100  $\mu\text{m}$



# Production of carbon nanofibers

- Creation of precursor by electrospinning
- Most often from PAN, it is also possible from PVA, PI, PVDF, or lignin
- Carbonization of fibers at temperatures above 1000 °C



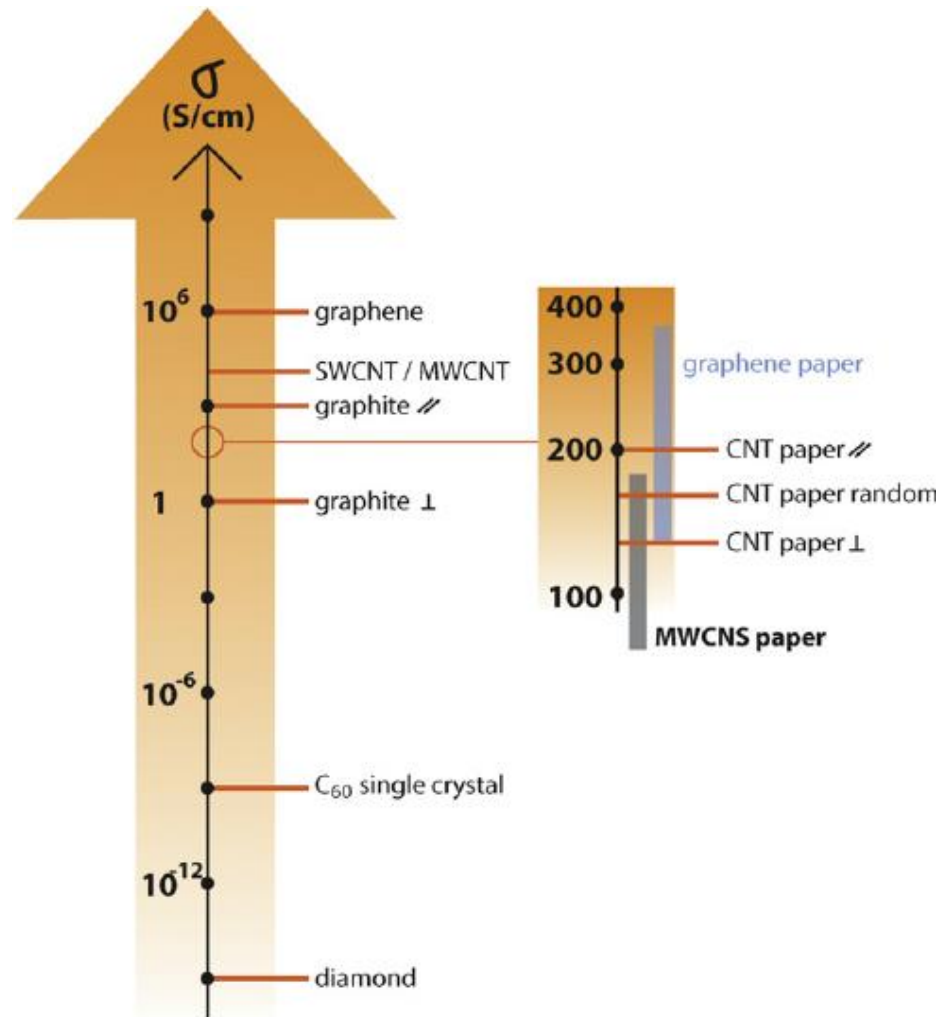
Transmission (a) and scanning (b) micrographs of carbon nanotubes on nanofibers produced by electrospinning of PAN, carbonization of PAN and catalytic growth of carbon nanotubes.

# Properties of carbon materials

Material	Young's modulus (GPa)	Tensile strength (GPa)
Epoxy	3.500	0.005
SWCNT	1054.000	150.000
MWCNT	1200.000	150.000
Steel	208.000	0.400
Wood	16.000	0.008

SWCNT, single-walled carbon nanotube; MWCNT, multi-walled carbon nanotube.

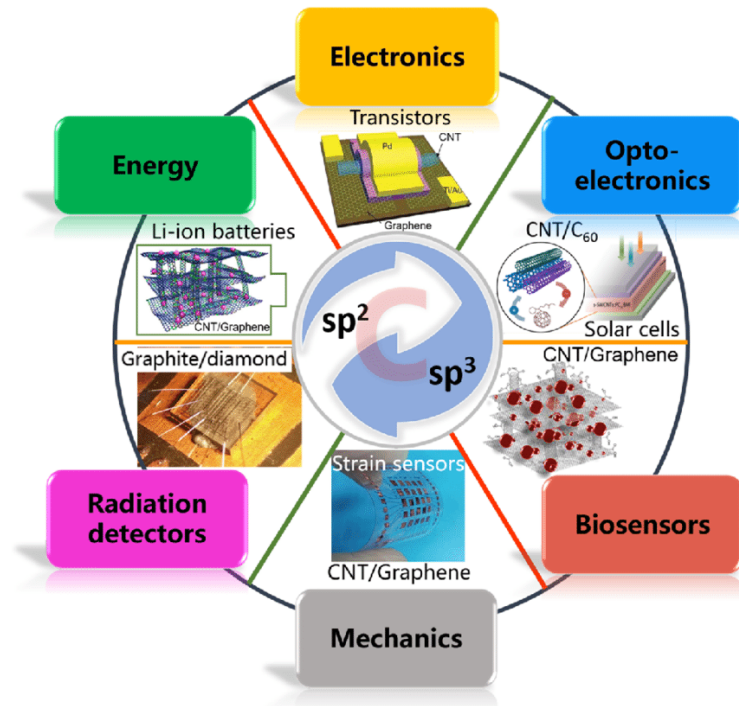
# Properties of carbon materials





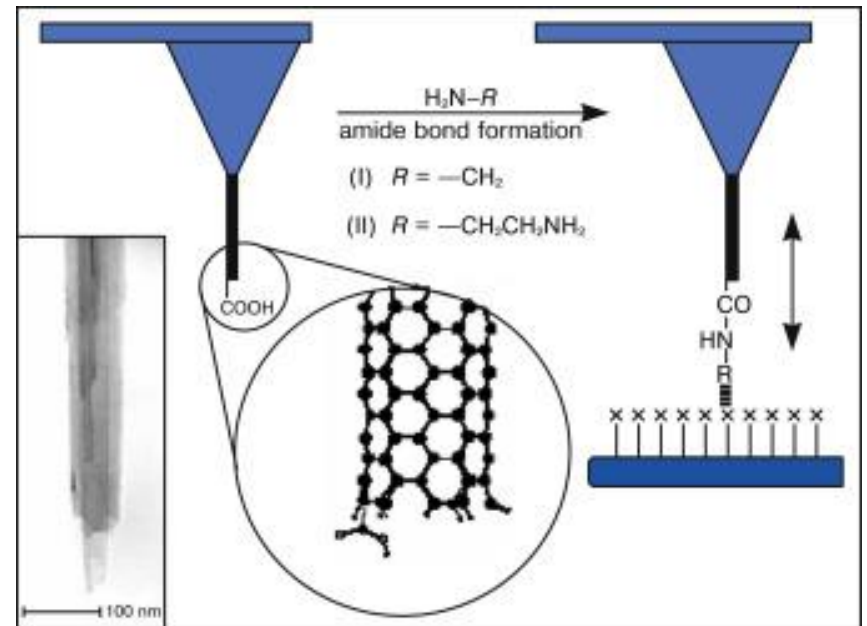
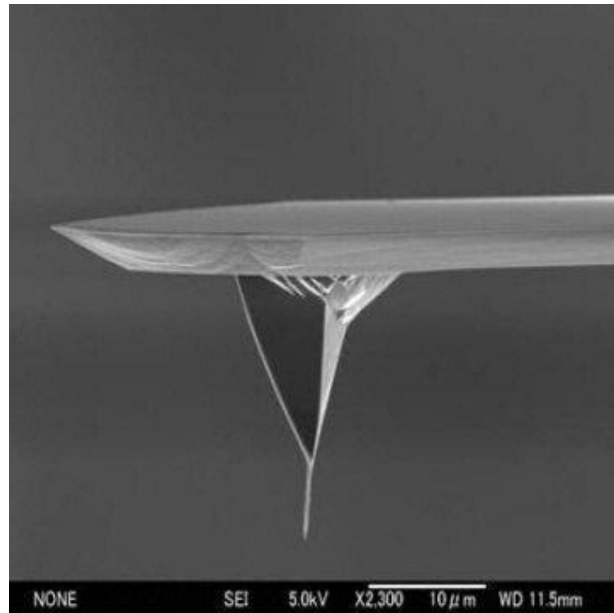
# Use of carbon nanomaterials

- Sensors
- Probes
- Catalyst supports
- Composite materials
- Conductive materials
- Antistatic coatings
- Non-flammable coatings
- Controlled drug delivery systems



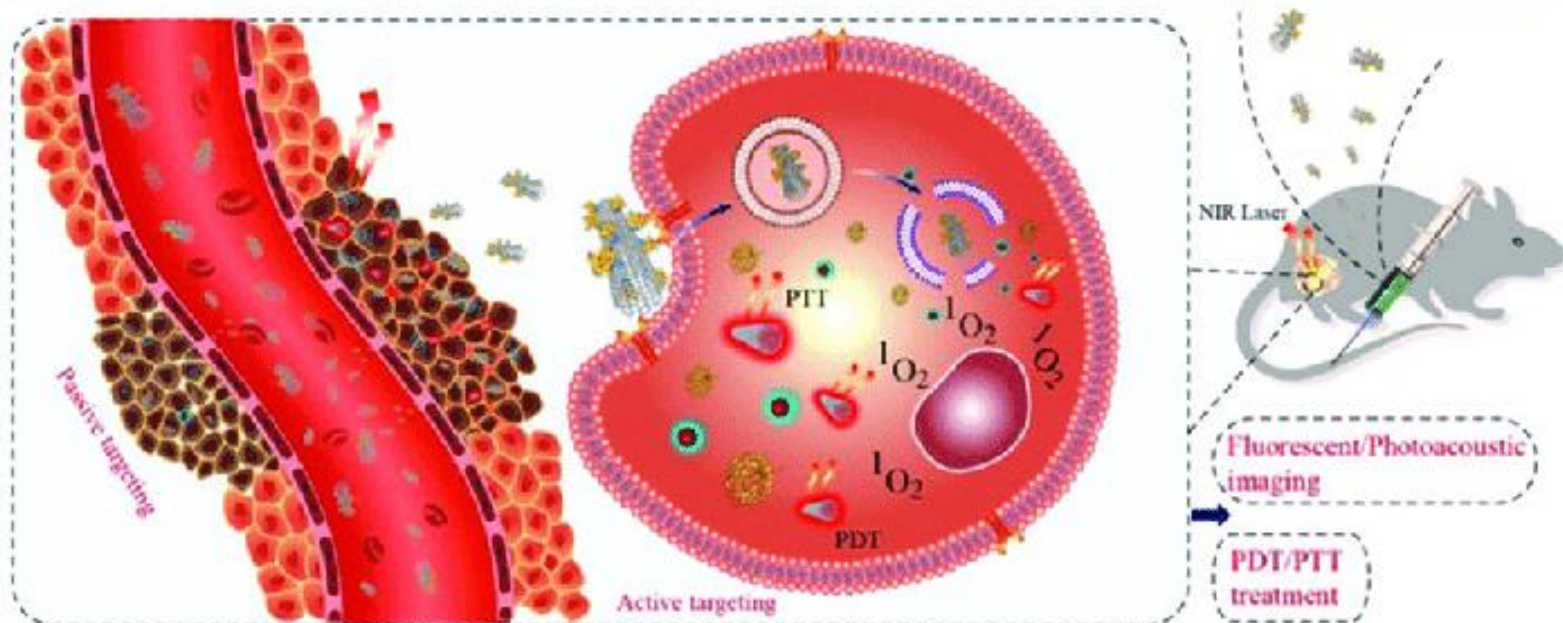
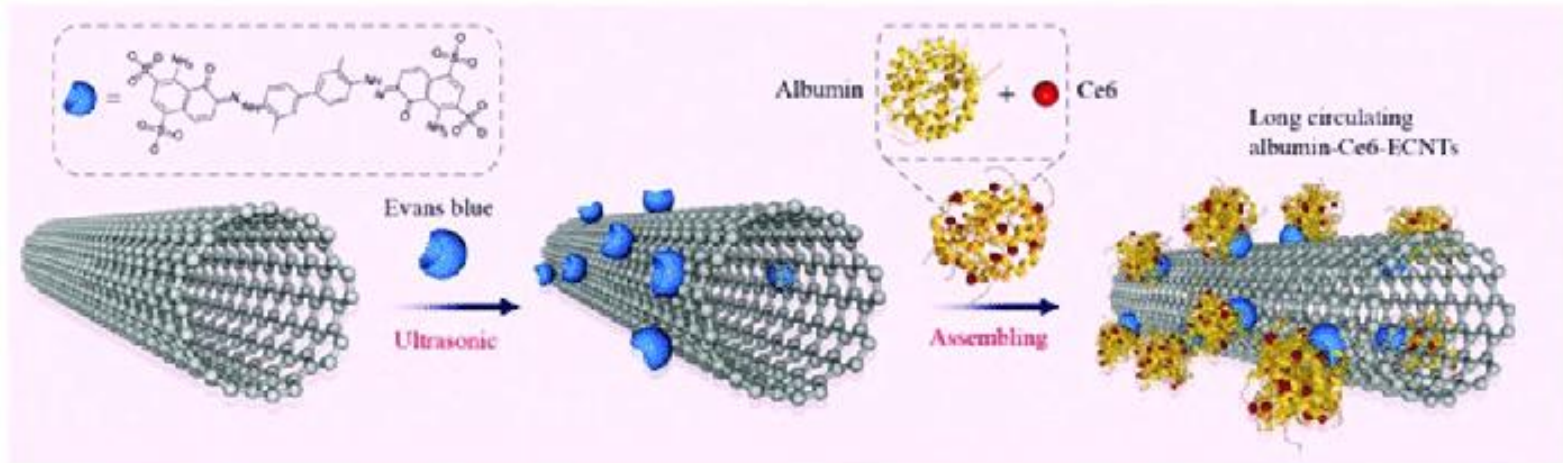
# Sensors, probes

- Use for AFM, for example
- The nanotube serves as a surface detector



Nanotube with functional chemical group as probe of cantilever of scanning atomic force microscope. Shown is probe movement for measurement of interaction energy between functional group and specimen surface.

# Controlled drug delivery



Enhanced drug accumulation

# Composite materials

- The nanotube serves as a reinforcement of the structure



Thank you for your attention!

# TEST

- What are the forms of carbon?
- What is graphite composed of?
- What are the types of carbon nanotubes?
- How can carbon nanofibers be made?
- What are carbon nanomaterials suitable for?