



# Szén nanocsövek

**Kürti Jenő**  
egyetemi tanár

Eötvös Loránd Tudományegyetem  
Biológiai Fizika Tanszék  
Budapest

„Az atomoktól a csillagokig” előadássorozat  
2006. február 2.

SZÉNATOMOK  
HATSZÖGES RÁCSA  
EGY  
HENGERPALÁSTON

**HOSSZ**  $\approx 1-100 \mu\text{m}$

de már állítottak elő

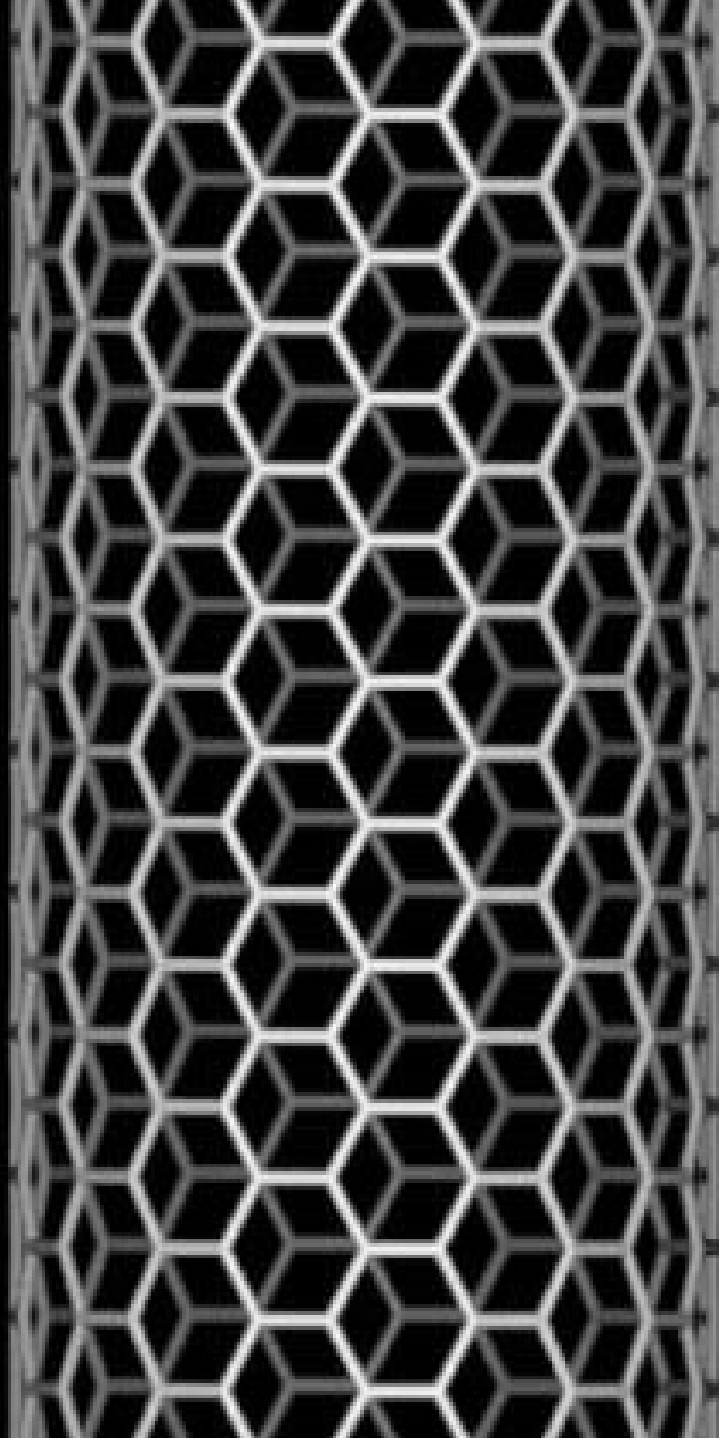
1-2 cm hosszúságút is !

Kb 50 ezerszer vékonyabb egy hajszálnál !

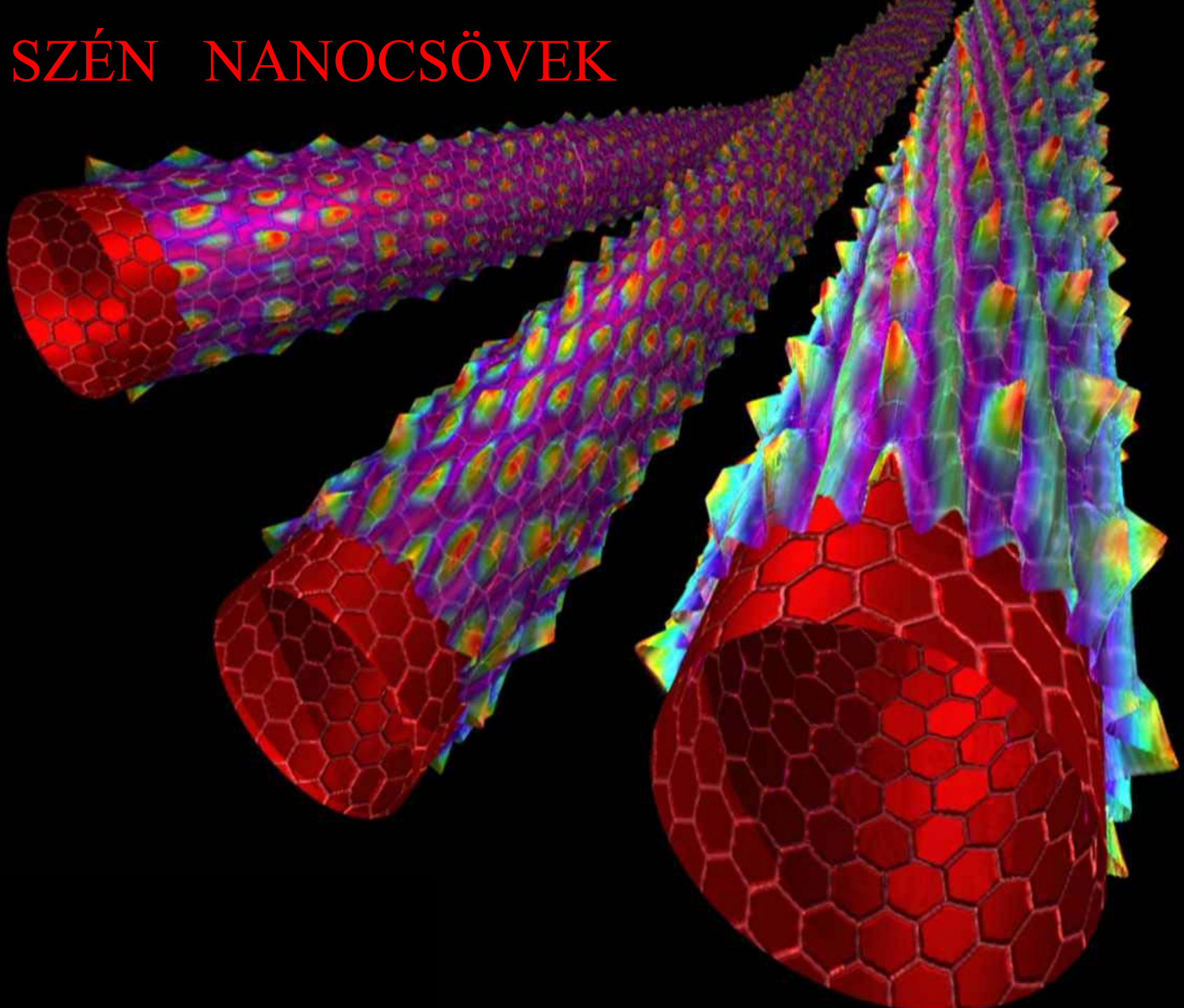
**ÁTMÉRŐ**  $\approx 1-1,5 \text{ nm}$



$1 \text{ nm} = 10^{-9} \text{ m} = 0,000000001 \text{ m}$

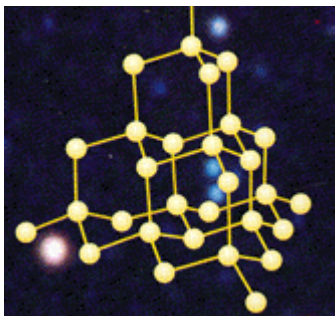


# SZÉN NANOCSÖVEK

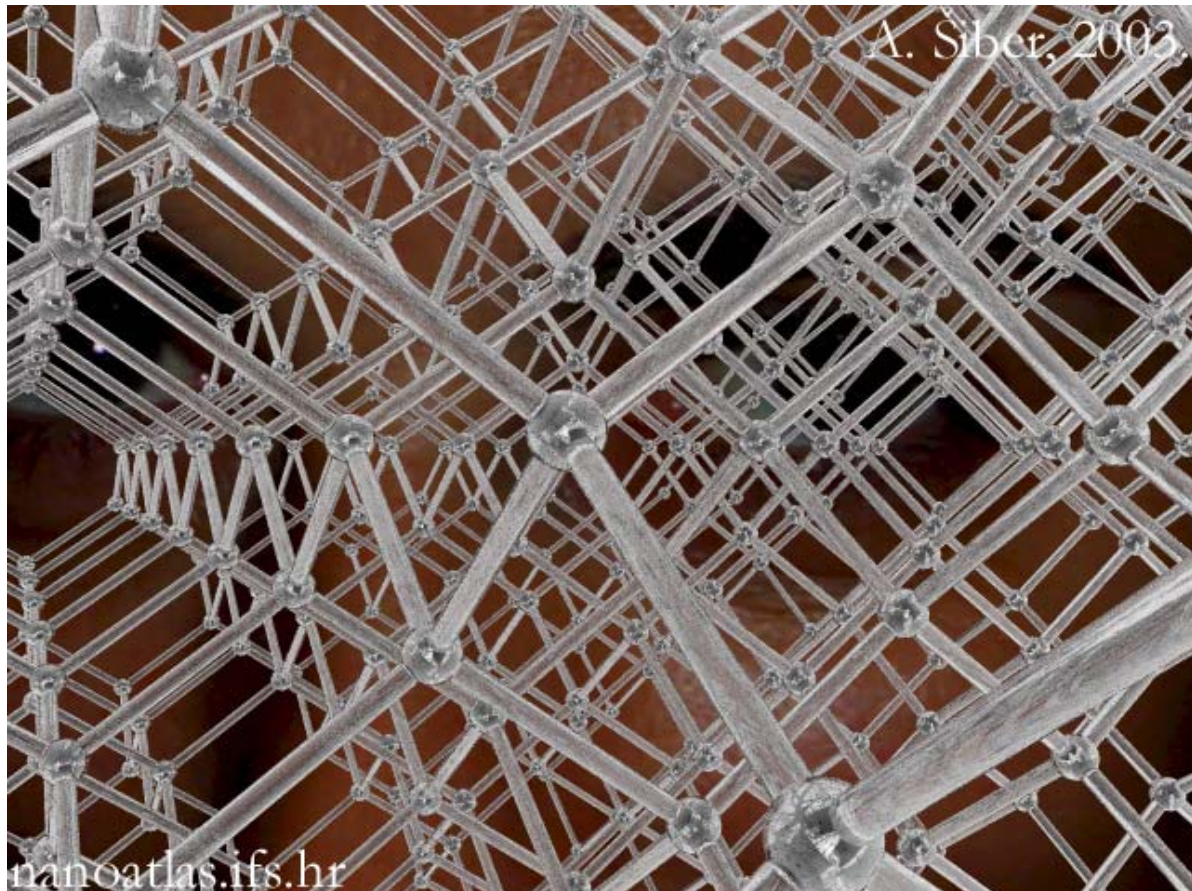




# GYÉMÁNT

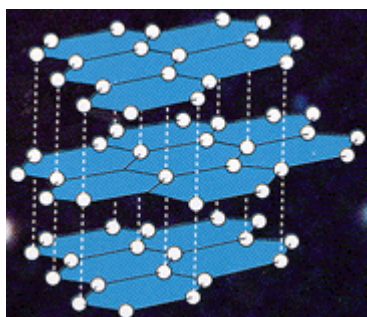


$$d_{CC} \cong 0,15 \text{ nm}$$

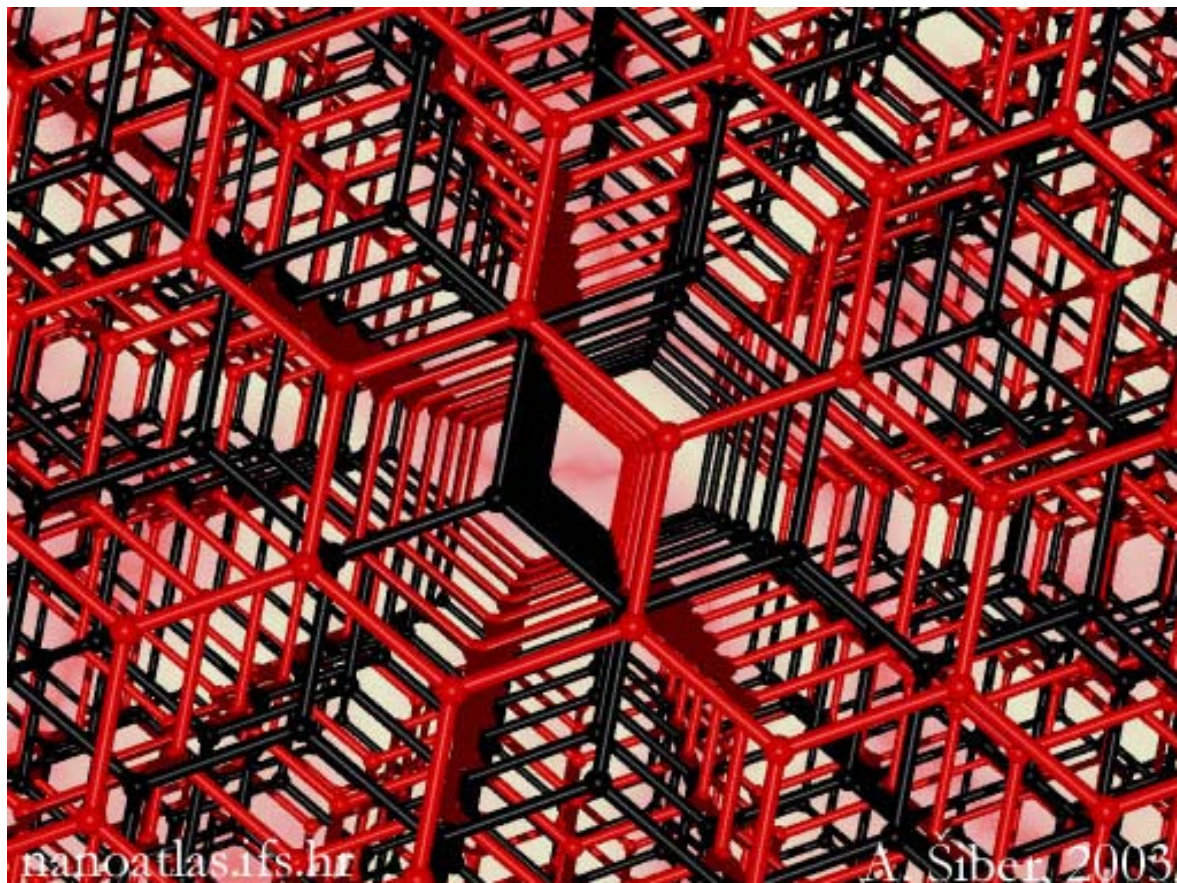




# GRAFIT



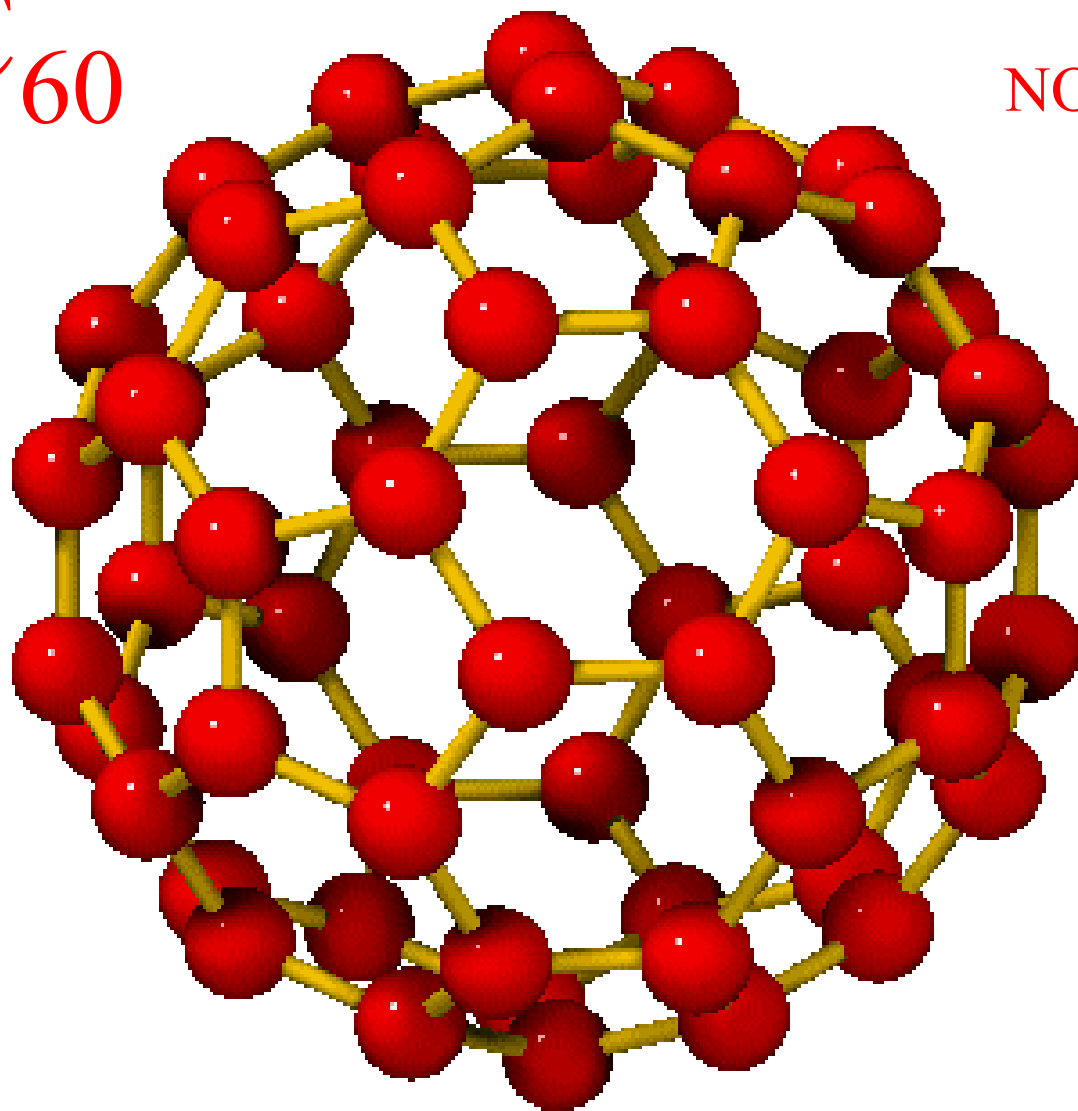
$$d_{CC} \cong 0,14 \text{ nm}$$



H.W.Kroto, J.R.Heath, S.C.O'Brien, R.F.Curl, R.E.Smalley,  
„C<sub>60</sub>: Buckminsterfullerene”, Nature 318, 162 (14 Nov. 1985)

C<sub>60</sub>

NOBEL-DÍJ: 1996-BAN



buckminsterfullerene

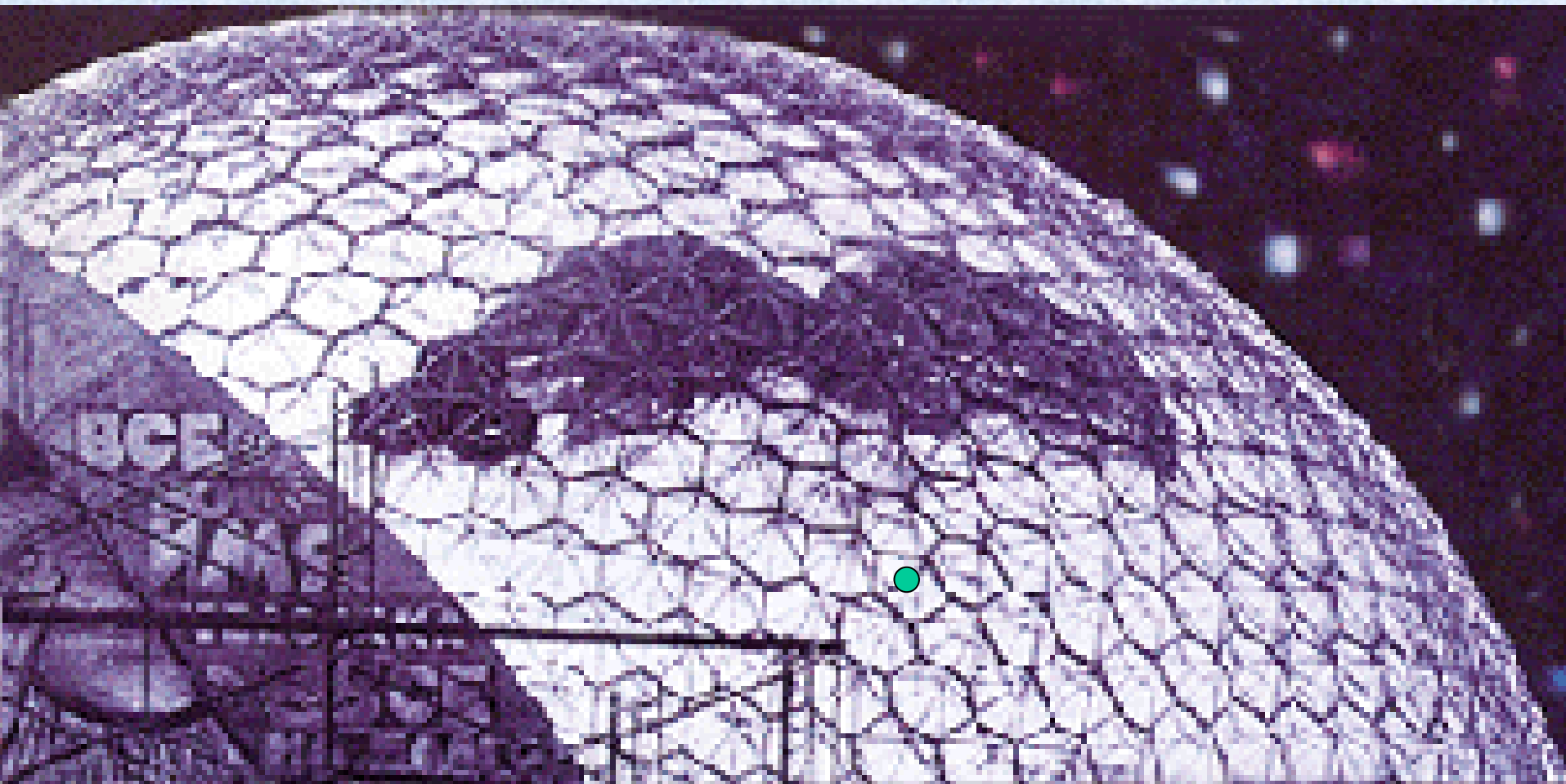
buckyball

$d \approx 0,7 \text{ nm}$

„focimolekula”

R. Buckminster Fuller  
amerikai építész (1895-1983)

pl. „geodétikus kupola” montreáli világkiállítás 1967

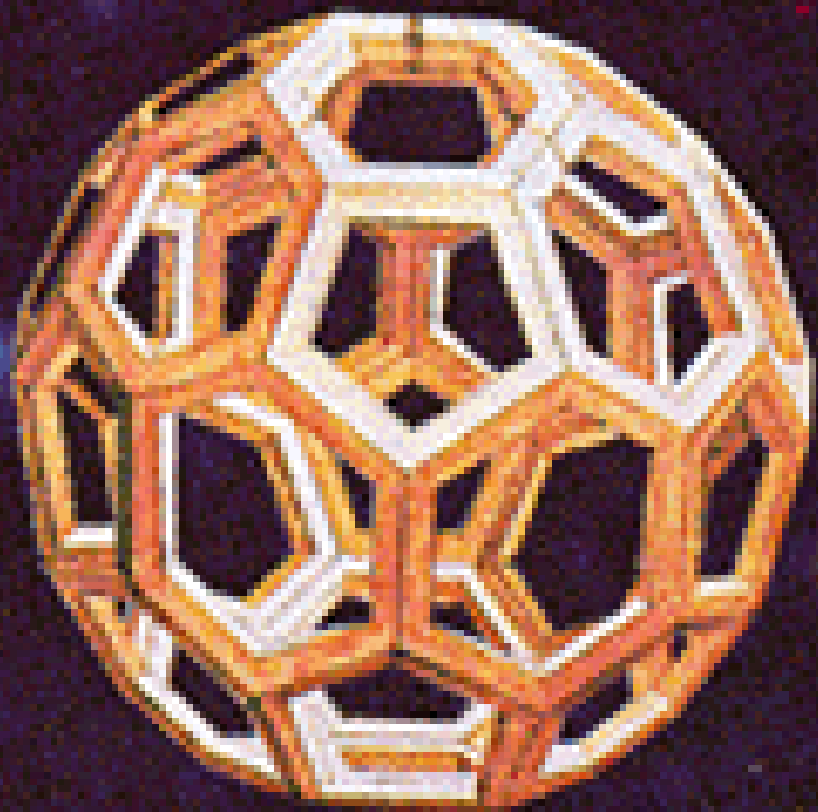
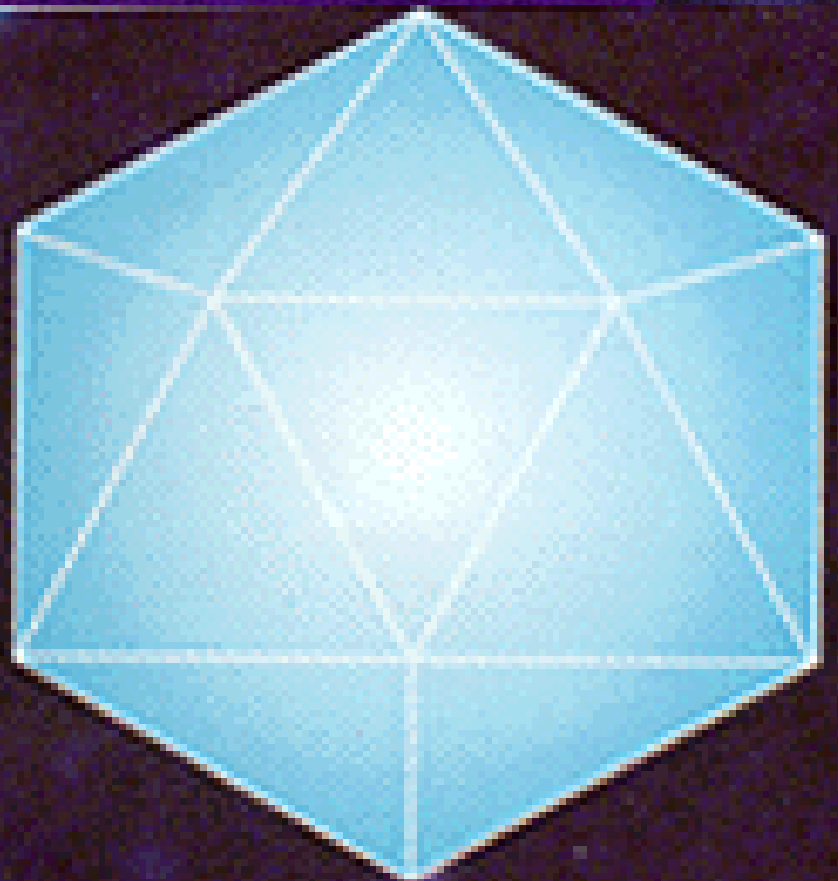




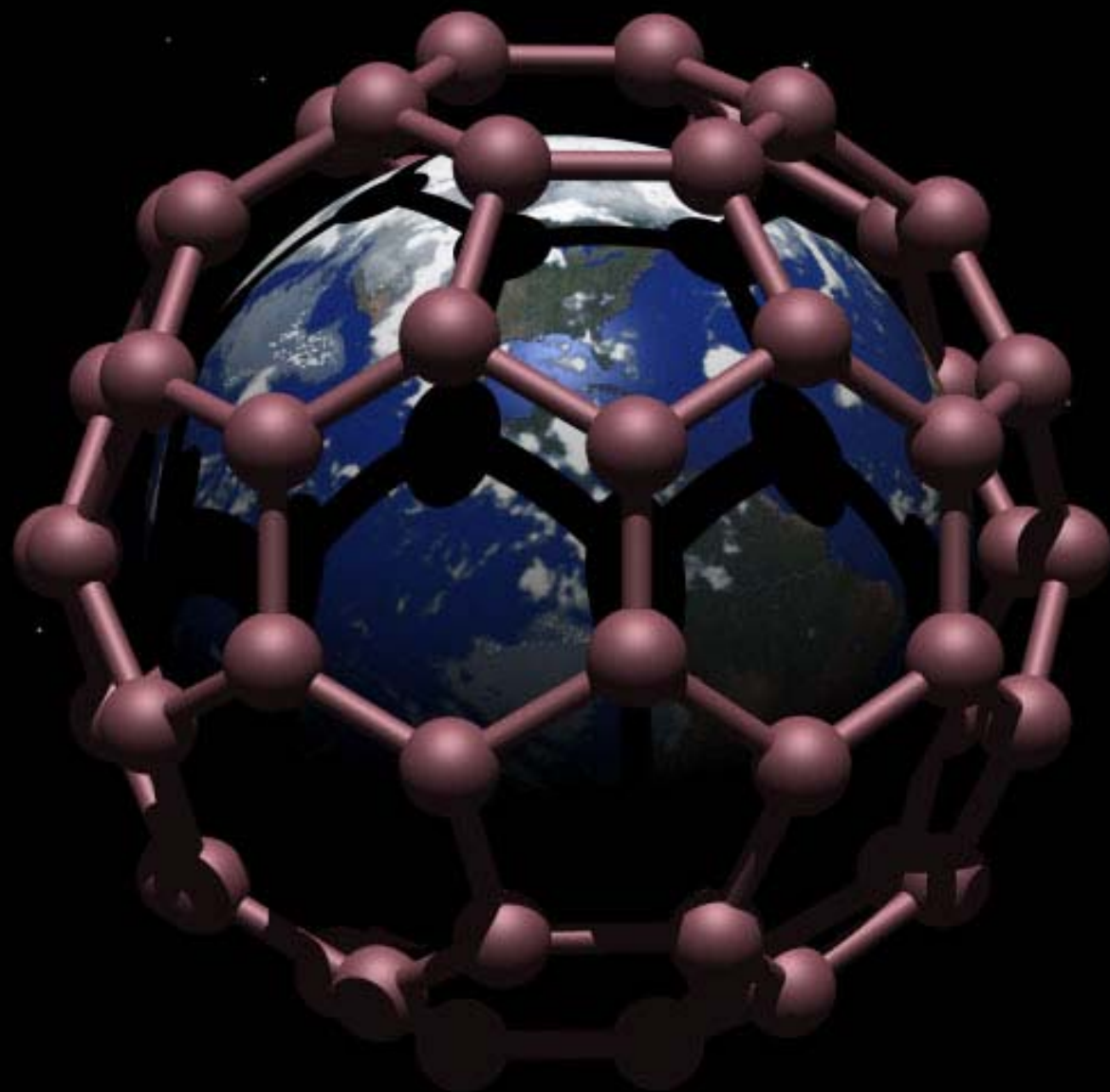
ikozaéder



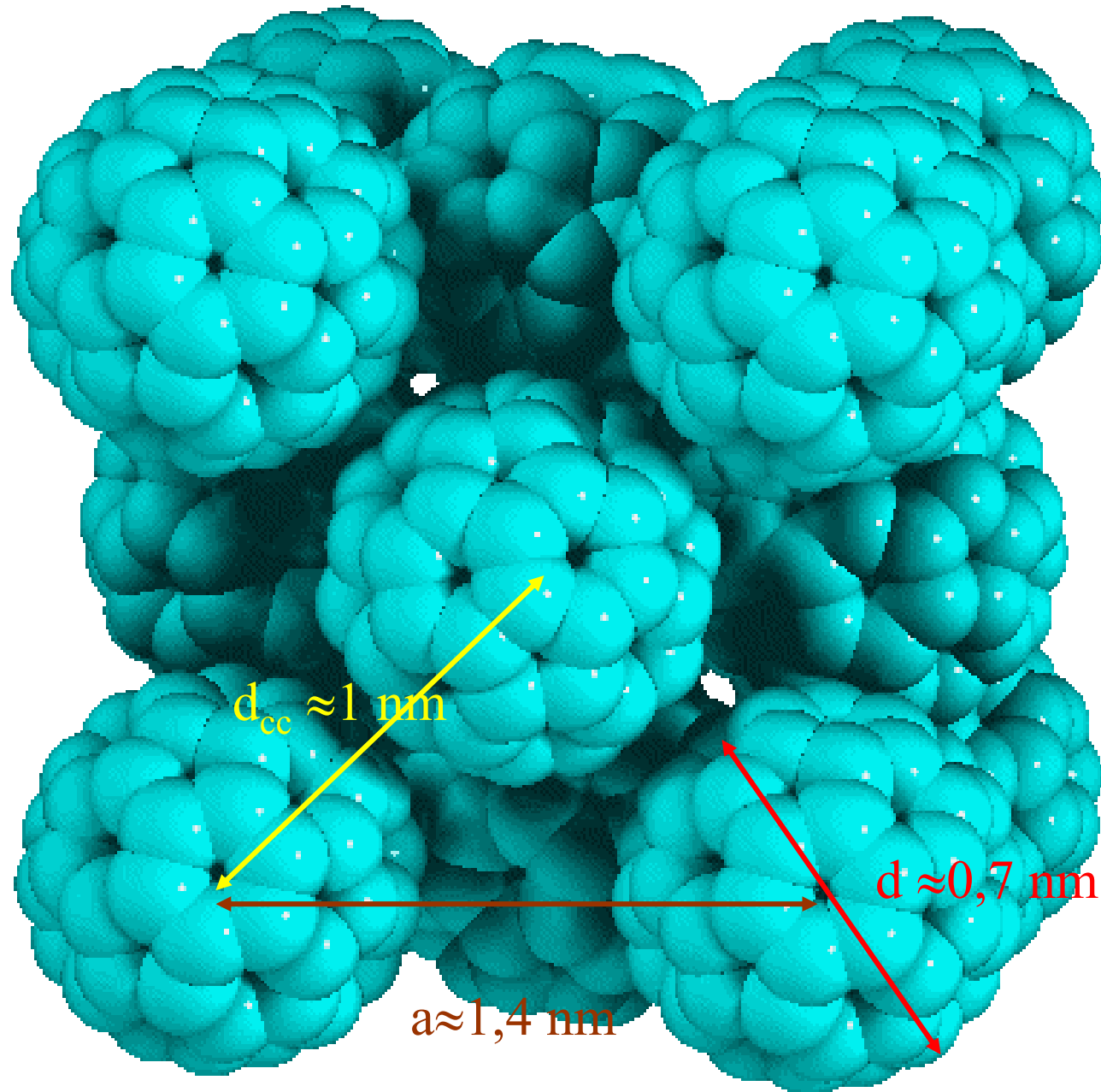
csonkolt ikozaéder



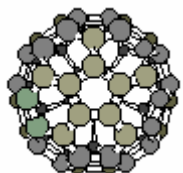


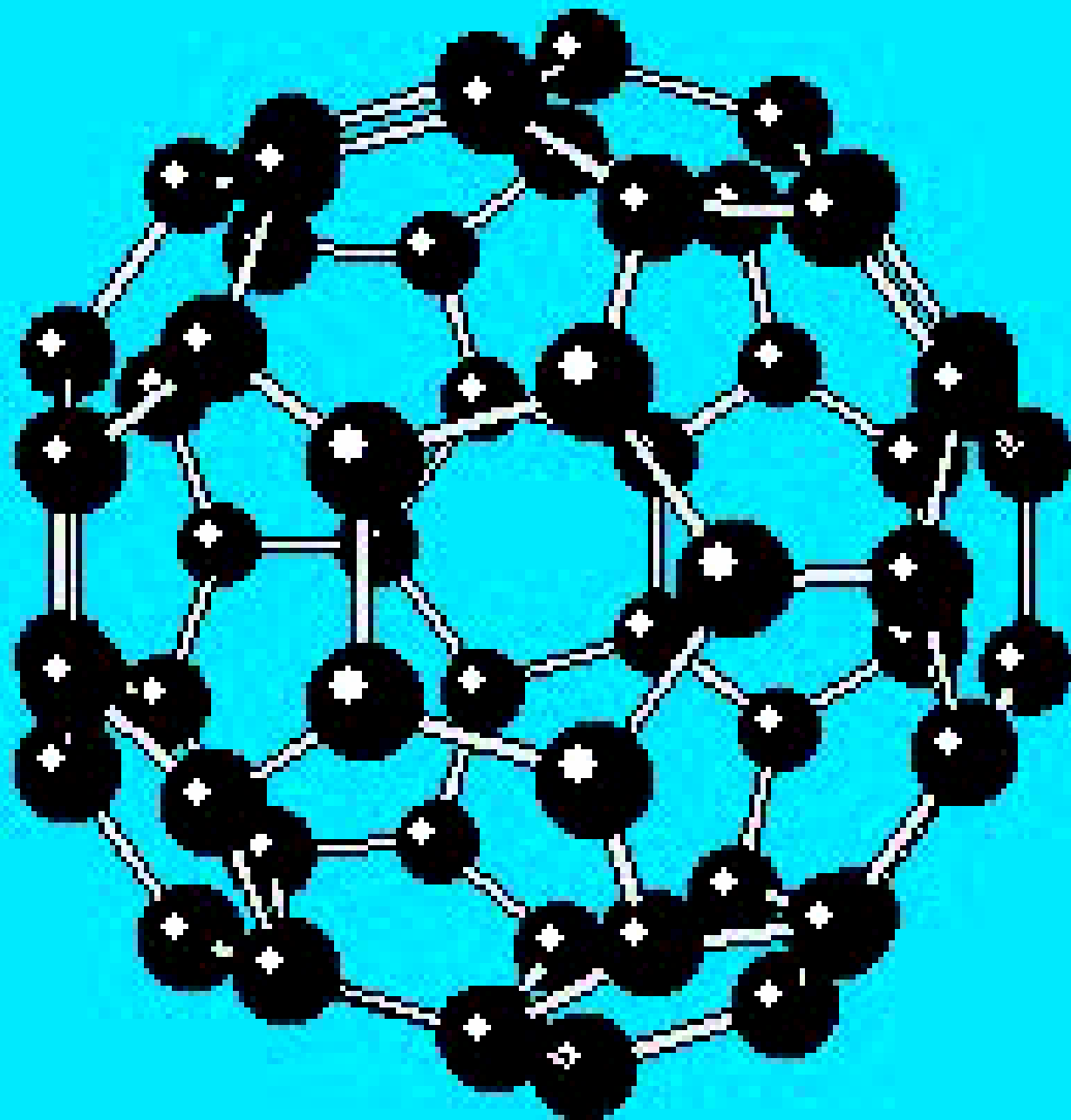


# $C_{60}$ lapcentrálalt köbös egykristálya (fullerit)

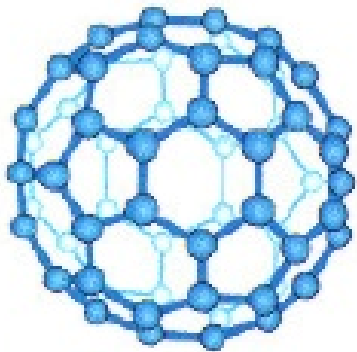


( $T_{\text{szoba}}$ )

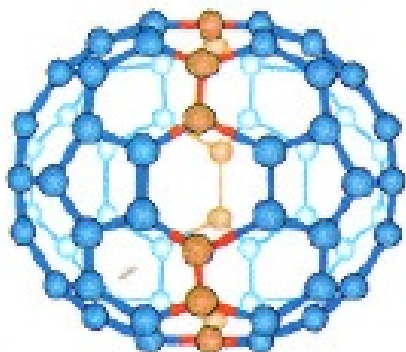




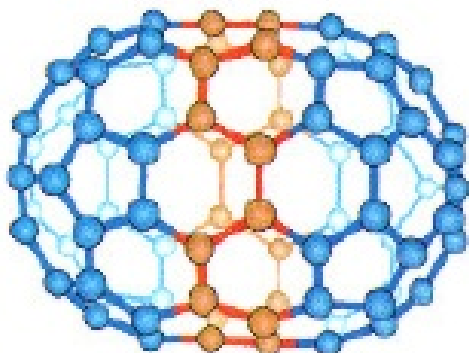




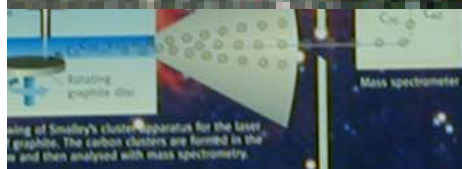
C<sub>60</sub>



C<sub>70</sub>



C<sub>80</sub>



Using of Smalley's cluster apparatus for the laser evaporation of graphite. The carbon clusters are formed in the laser and then analysed with mass spectrometry.

### Graphite and diamond – soft and hard

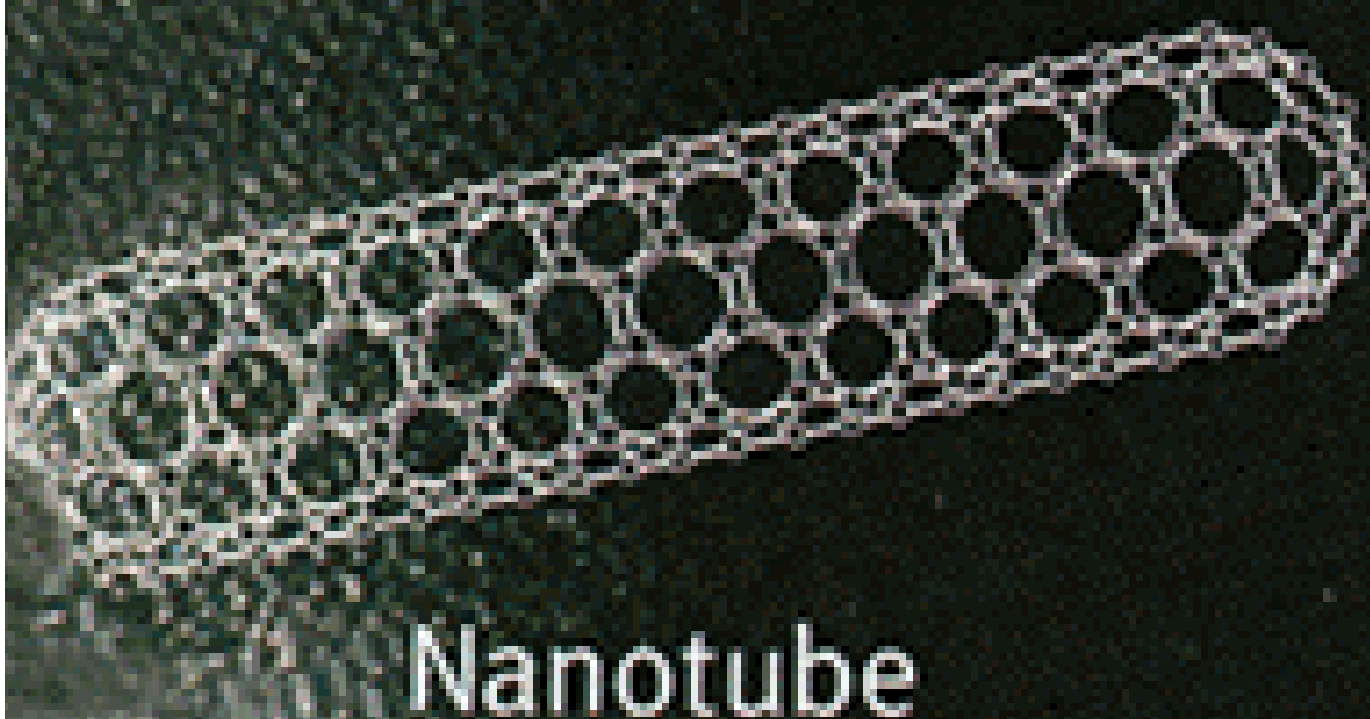
Graphite is soft and black and the stable, common form of carbon. Diamond is hard and transparent and the unusual form of carbon. In diamond each carbon atom is bonded to four other carbon atoms in a regular repetitive way. The density is 3.51 g/cm<sup>3</sup>. In graphite the carbon atoms are located at the corners of regular and fused hexagons arranged in parallel layers. Its density is considerably lower, 2.26 g/cm<sup>3</sup>.



Graphite

Diamond

Source: <http://www.kva.se> - Jim Riggall, Perfect Symmetry: The Accidental Discovery of an Adventure in Chemistry, Aurant Press, London, 2005, 18 + 260 pp.  
 E. Smalley, Great Balls of Carbon: The Story of Buckminsterfullerene, The Sciences Group,



# Nanotube

Carbon ball with a metal core

### Useful fullerenes?

C<sub>60</sub> can easily accept electrons and form negative ions. With alkali metals (e.g. potassium), C<sub>60</sub> forms a new superconducting crystalline material built from a C<sub>60</sub> ion with three charges and three positive potassium ions (K<sub>3</sub>C<sub>60</sub>). The material becomes superconducting at 19 K. Because C<sub>60</sub> can accept and then donate electrons reversibly, the fullerenes may well become catalysts in chemical processes and replace expensive and poisonous metals.

By a modification of the method for fullerene production, it is now possible to produce the world's smallest tubes – nanotubes – from pure carbon. The tubes form extremely small diameters, approximately 1 nanometre. They can be closed at one end or both ends. These new materials might find applications in the electronics industry due to their unique electrical and mechanical properties.

During the six years since the fullerenes became readily available to scientists, more than a thousand new compounds have been synthesized and their chemical, optical, mechanical or biological properties have been tested. The production of fullerenes is still very expensive, which limits their use.

Tubes there are more than one hundred fullerene patterns, but a large-scale commercial use for these exciting fullerenes is still to be found.

Nanotube

### Fullerenes in quantities

Five years after the discovery of the fullerenes, the atmosphericists D. R. Huffman and W. Kutzschner and their co-workers managed to produce fullerenes in larger quantities.

When two rods of graphite are heated to a high temperature by an electric arc discharge in an atmosphere of helium at a pressure of 13 MPa the graphite rods are slowly consumed and soot is formed. Approximately 30% of the soot is made up of C<sub>60</sub> and C<sub>70</sub>. The soot is separated and treated with benzene to dissolve the fullerenes, which can then be separated using chromatographic methods.

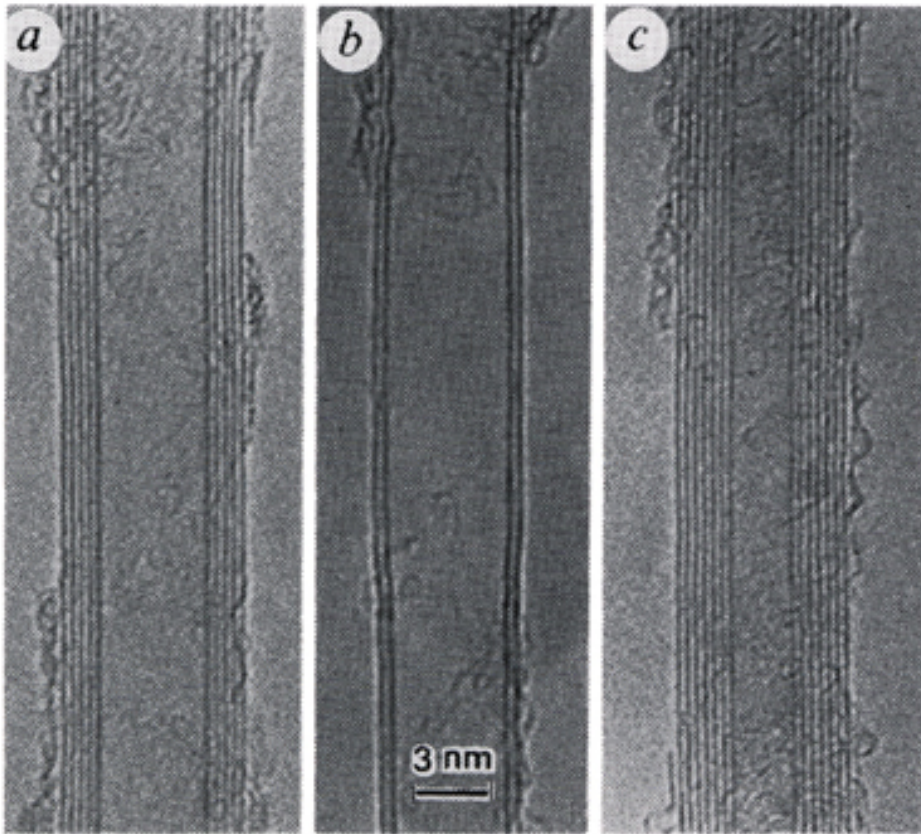
### C<sub>60</sub> in nature

Molecular weight: 720  
Molecular diameter: 0.35 nm  
The 60 carbon atoms in their arrangement, the molecule is spherical, which confers its high strength. It is 1470, 1475, 1710 and 1715 pm in diameter (1 pm is equivalent to 10<sup>-12</sup> m).

**KUNGL. VETENSKAPSAKADEMIEN**  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Editors: Ingrid Nilén-Rasmussen and Margareta Wilberg-Rohlfed, The Royal Swedish Academy of Sciences, Dept. of Organic Chemistry, Chemistry Research Centre, Uppsala, S-751 22, and Margareta Wilberg-Rohlfed, Dept. of Organic Chemistry, Uppsala University, Uppsala, S-751 22, and Margareta Wilberg-Rohlfed, The Royal Swedish Academy of Sciences, Information Department, Box 500, SE-751 20 Uppsala, Sweden. Tel +46 8 473 23 00, fax +46 8 47 31 76.

Printing and distribution: **VOLVO**

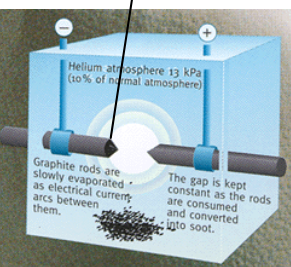


# MWCNT

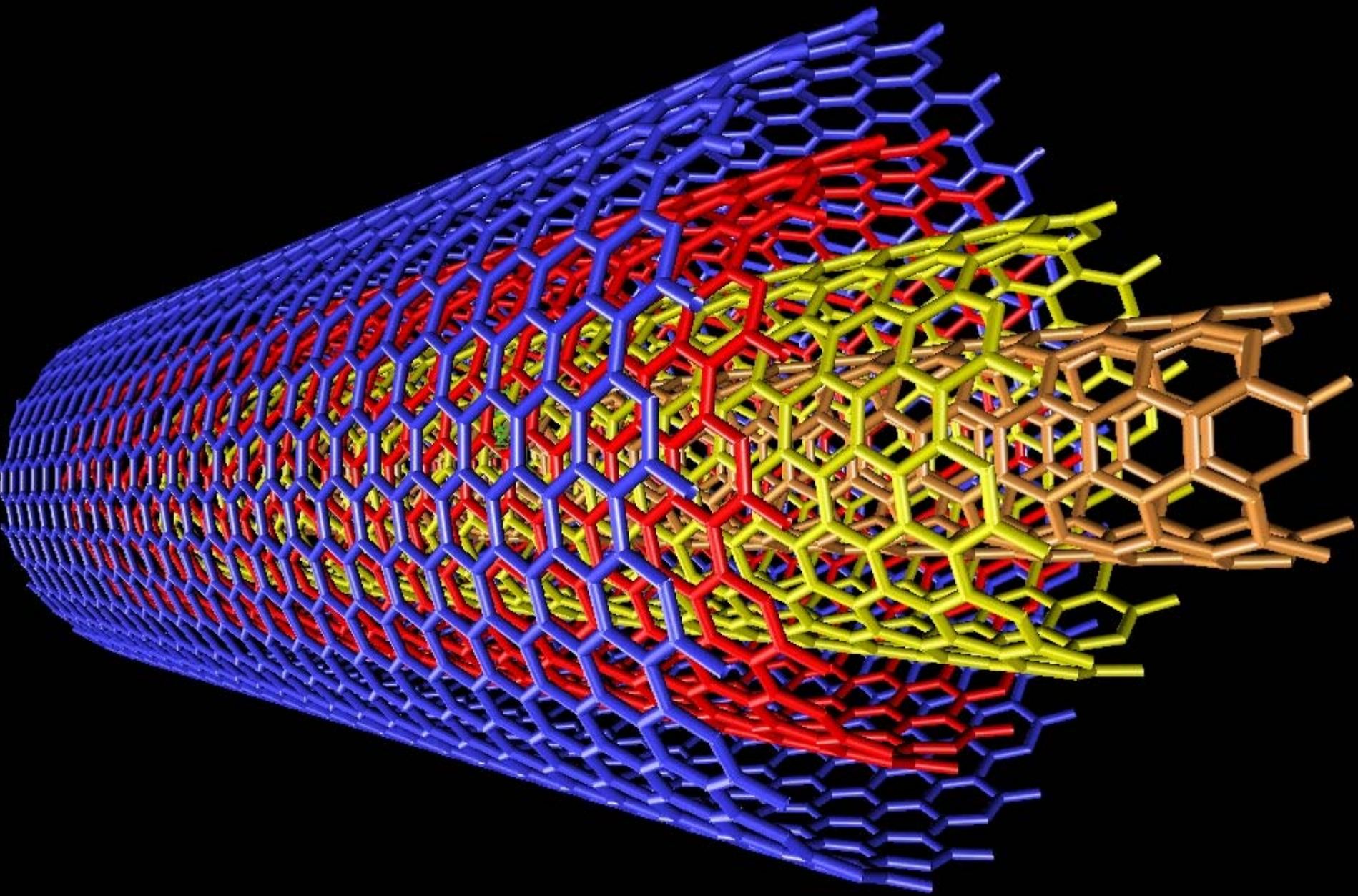
sokfalú (koncentrikus)  
szén nanocsövek  
felfedezése

(TEM)

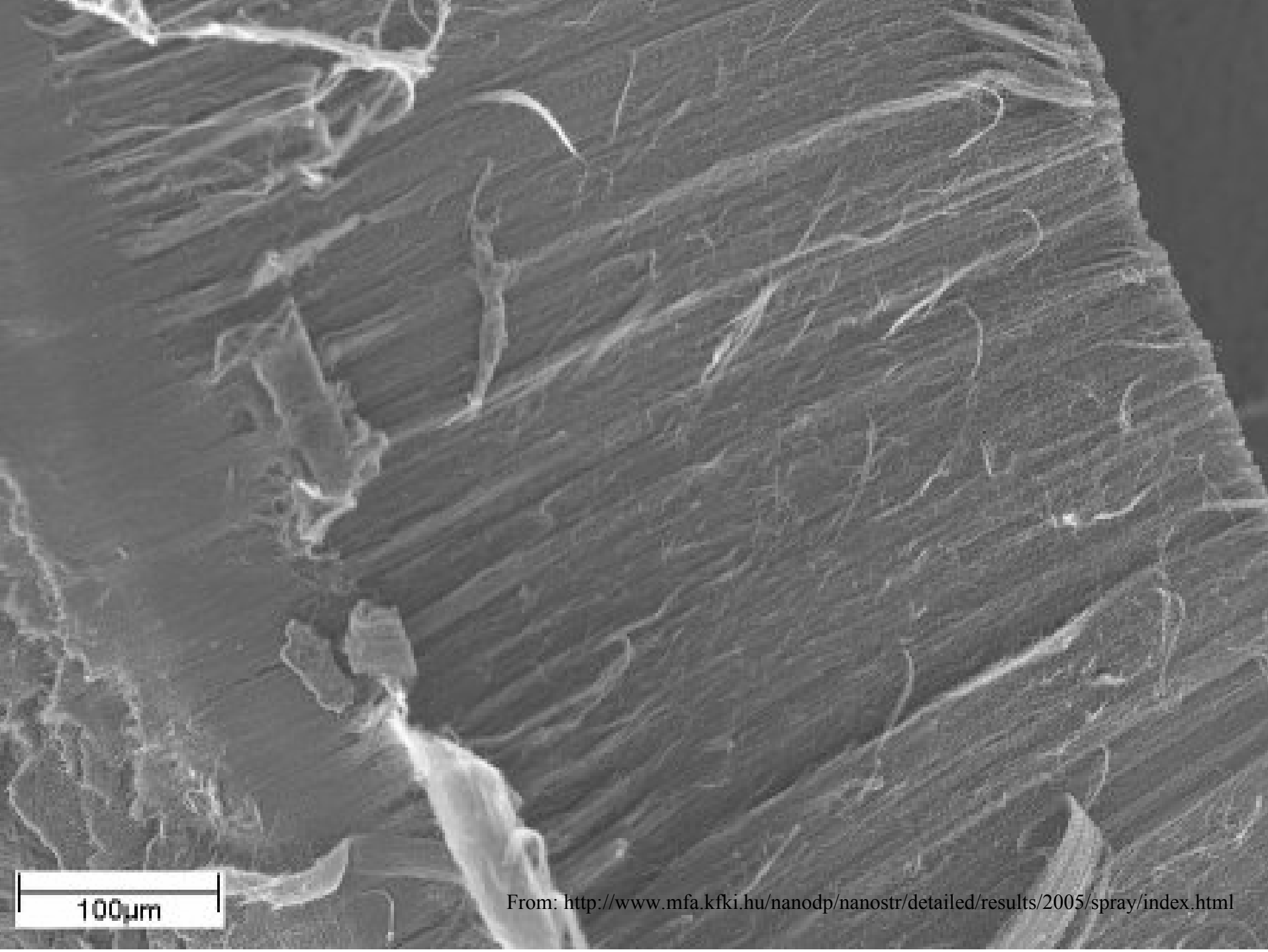
S.Iijima, Nature 354, 56 (1991)





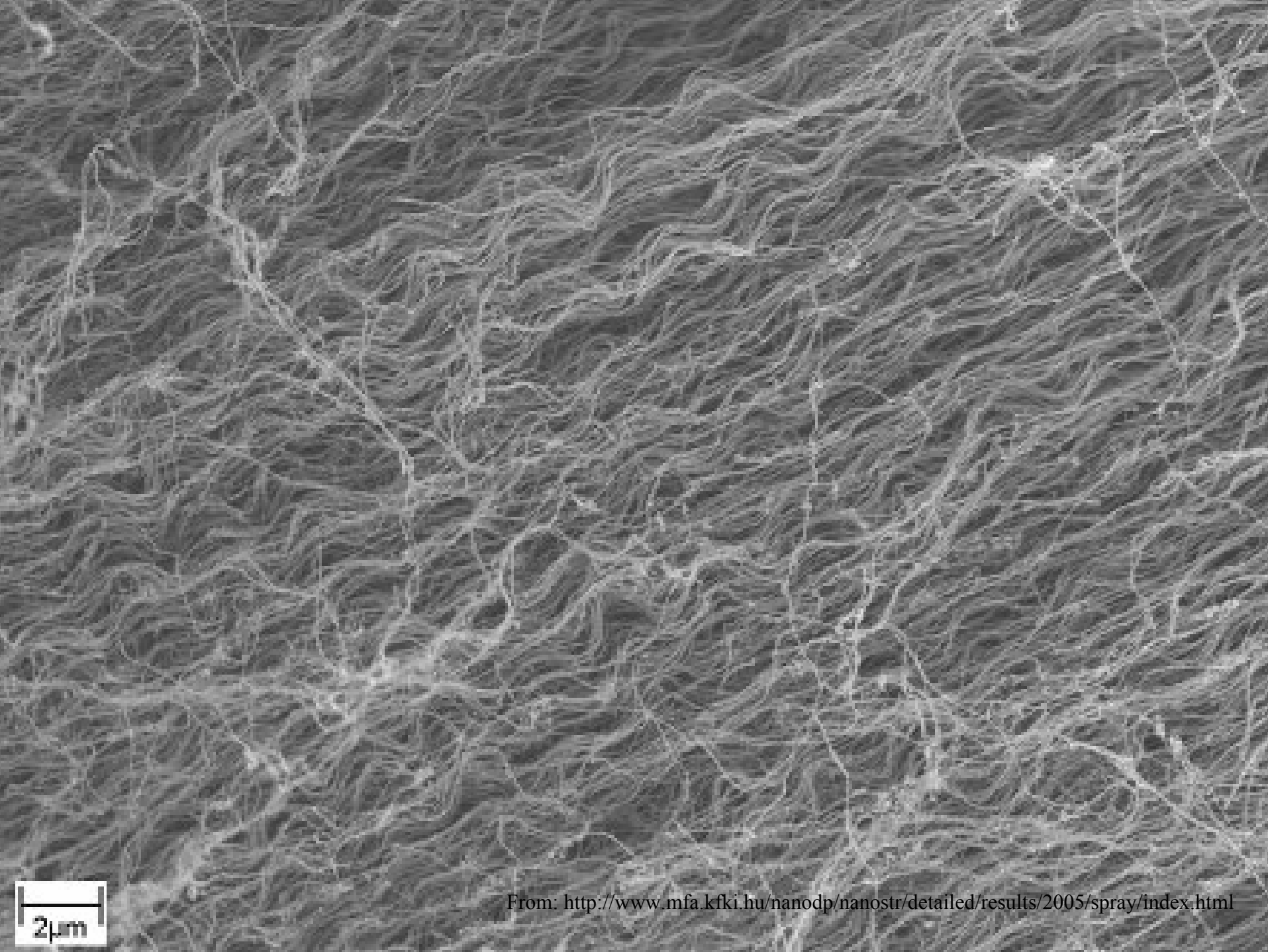




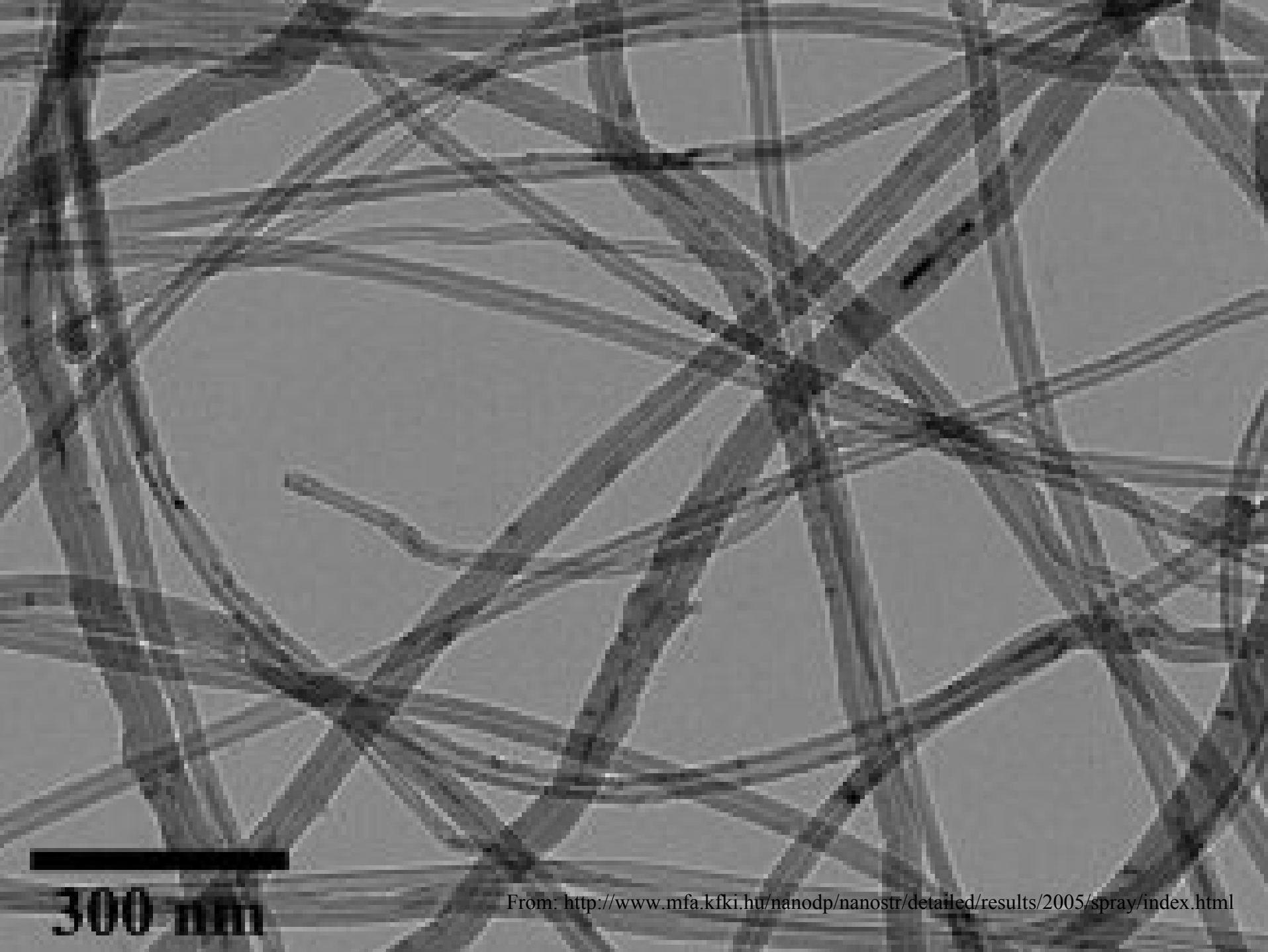


100µm

From: <http://www.mfa.kfki.hu/nanodp/nanostr/detailed/results/2005/spray/index.html>



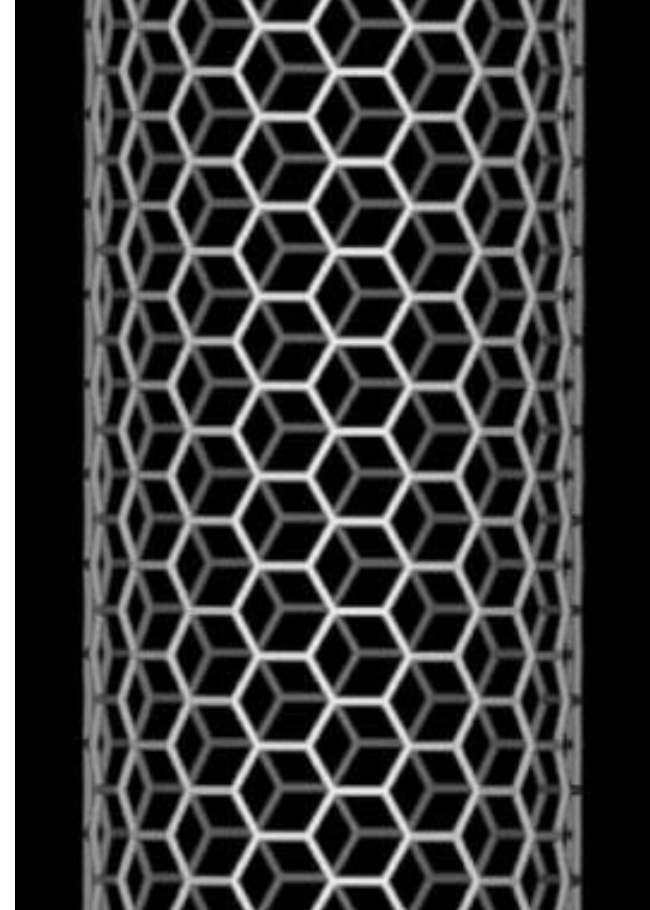
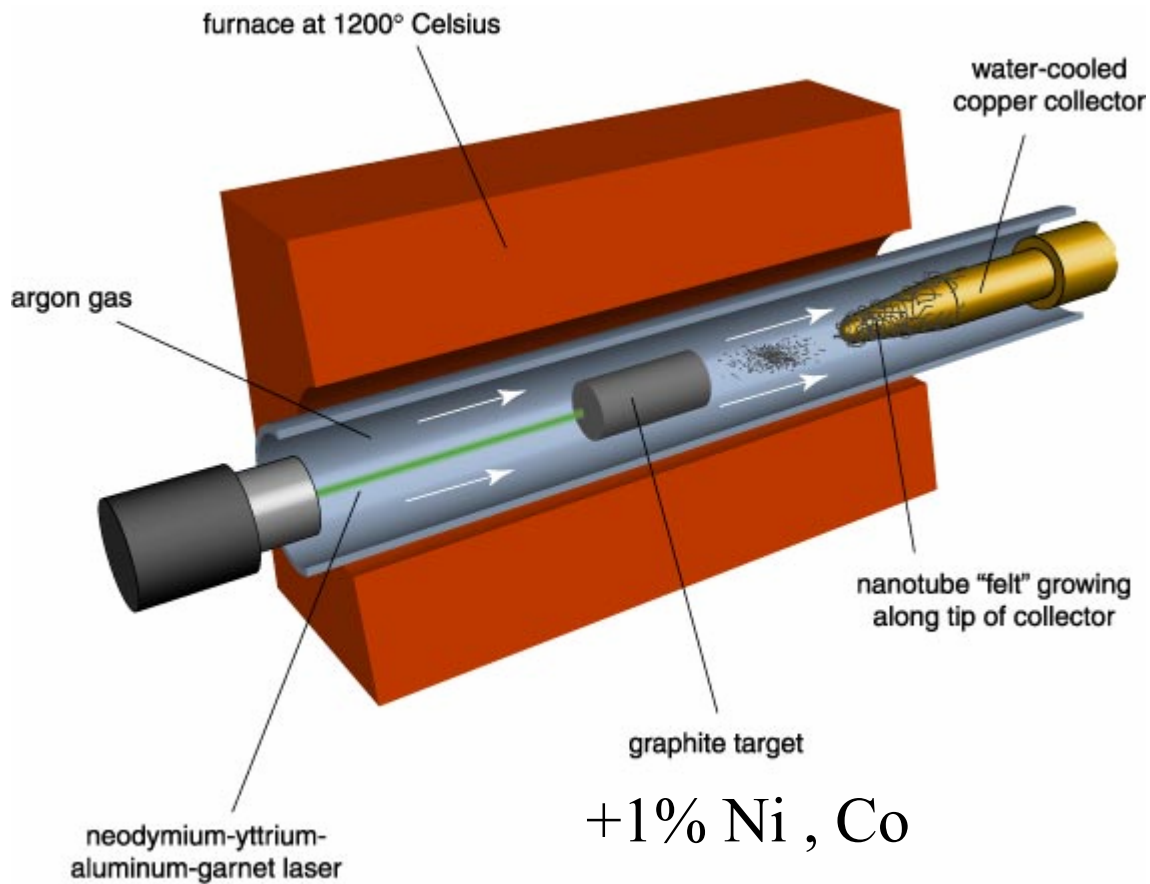
From: <http://www.mfa.kfki.hu/nanodp/nanostr/detailed/results/2005/spray/index.html>



**300 nm**

From: <http://www.mfa.kfki.hu/nanodp/nanostr/detailed/results/2005/spray/index.html>



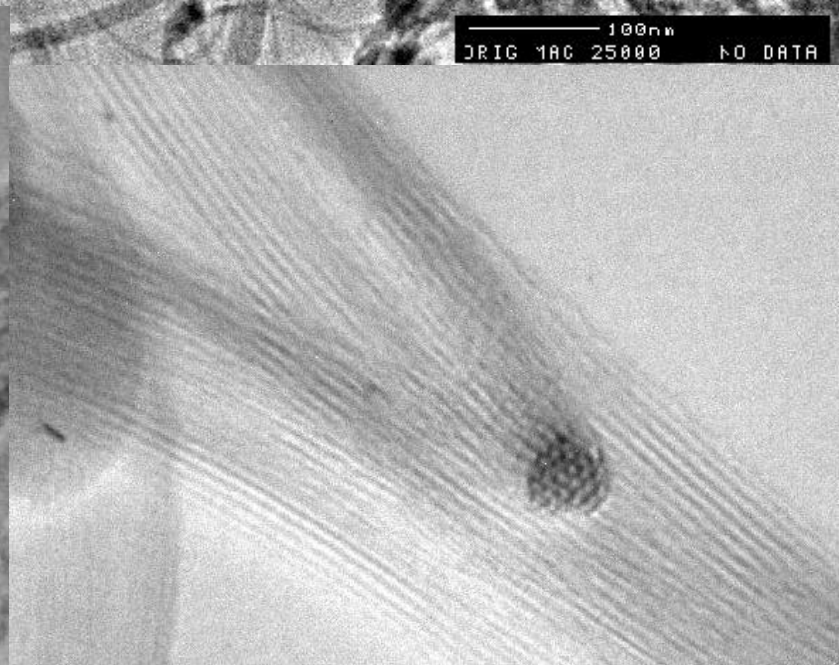
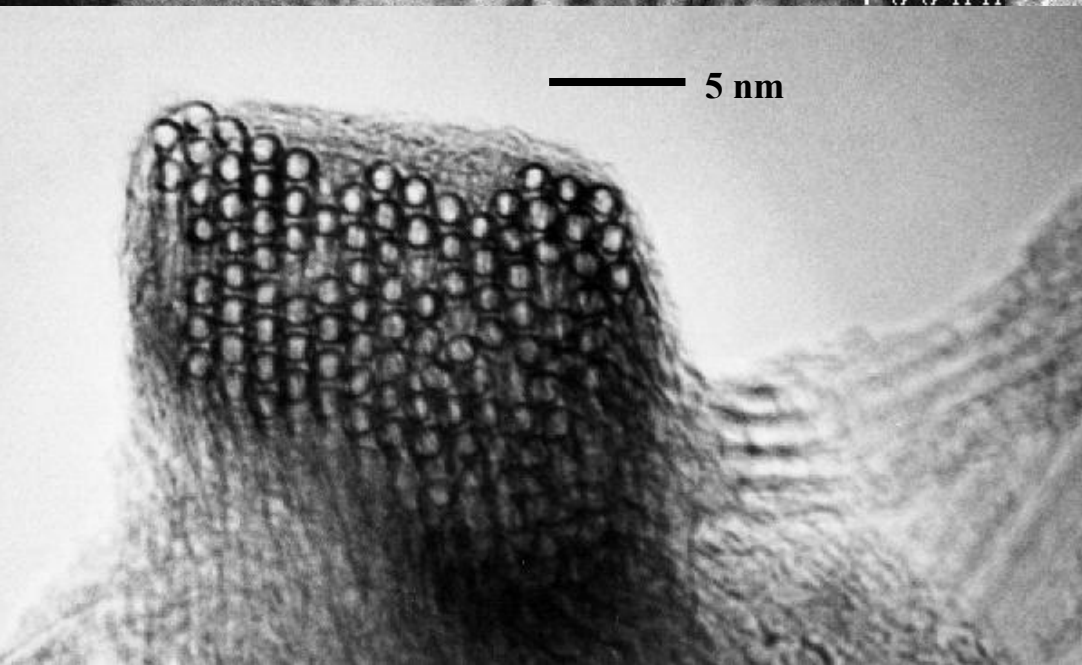
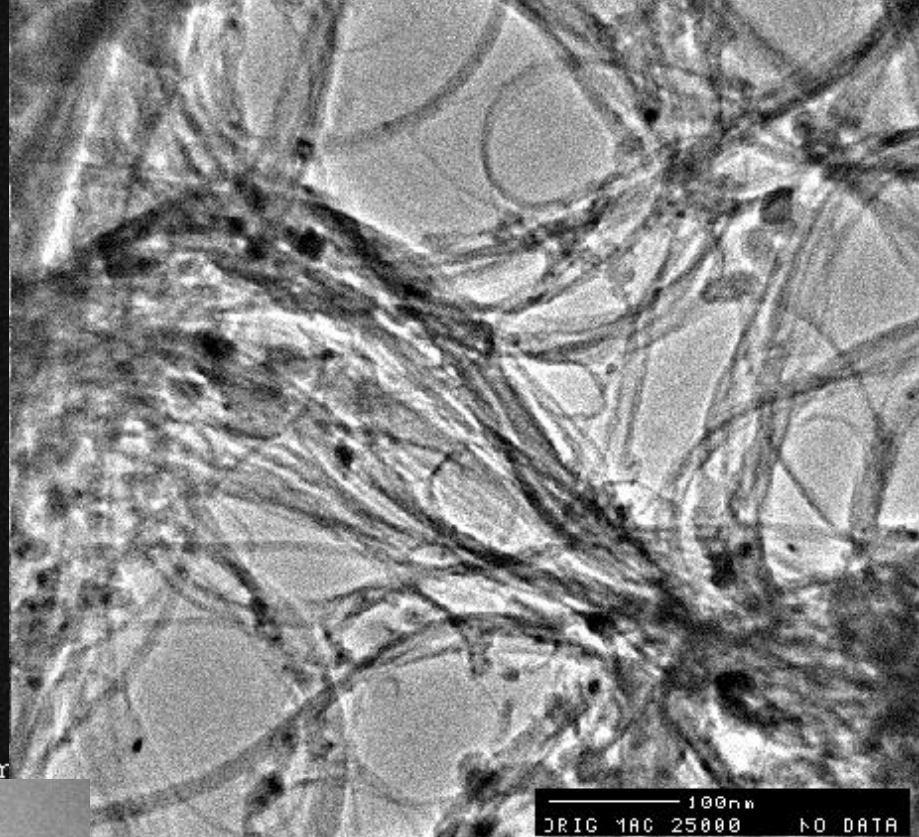
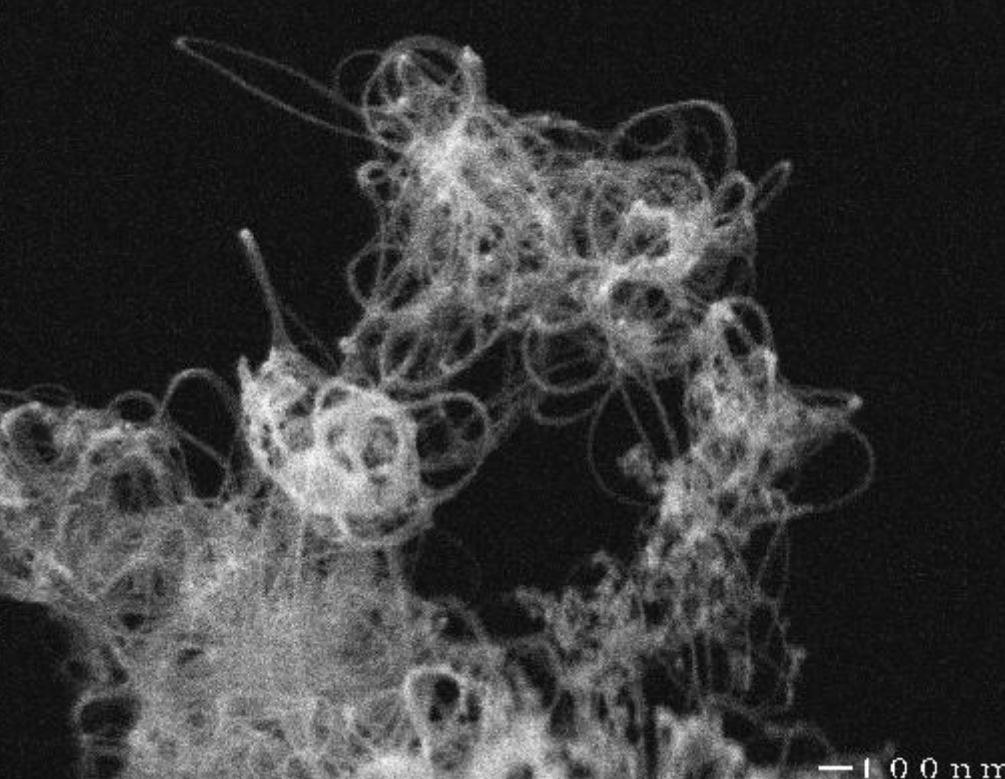


# SWCNT

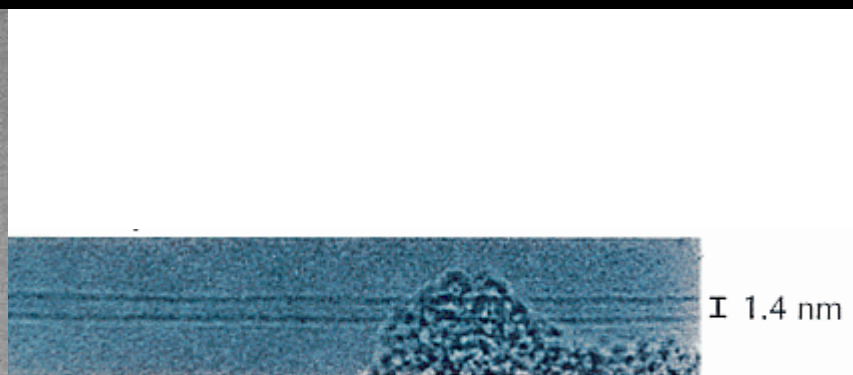
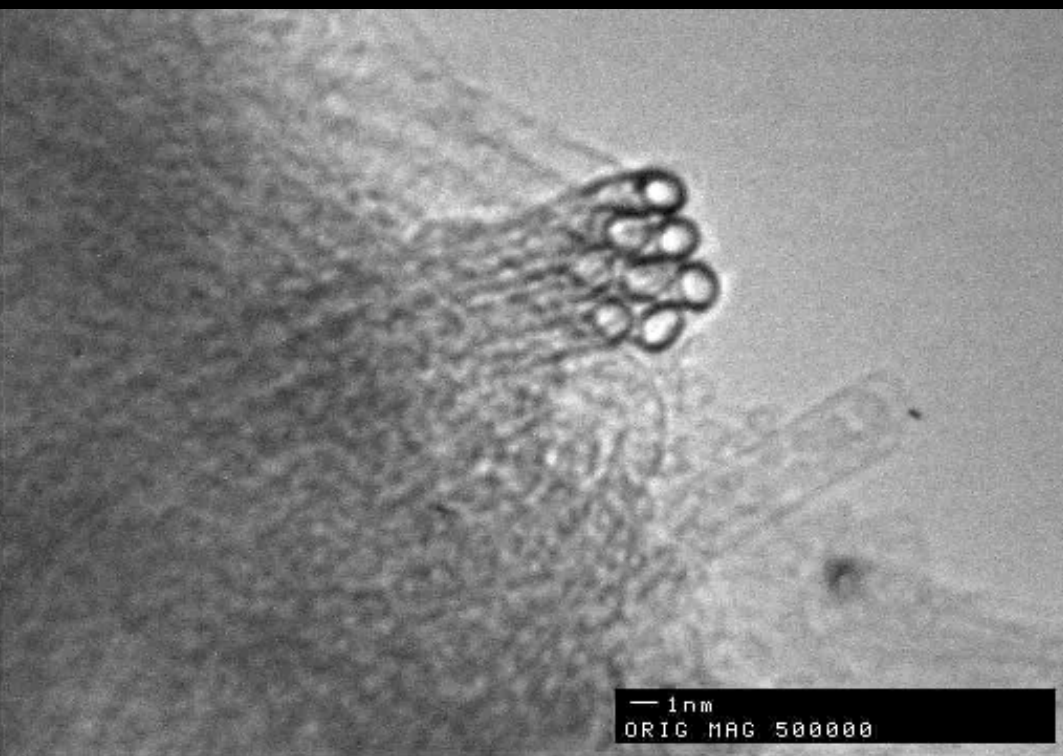
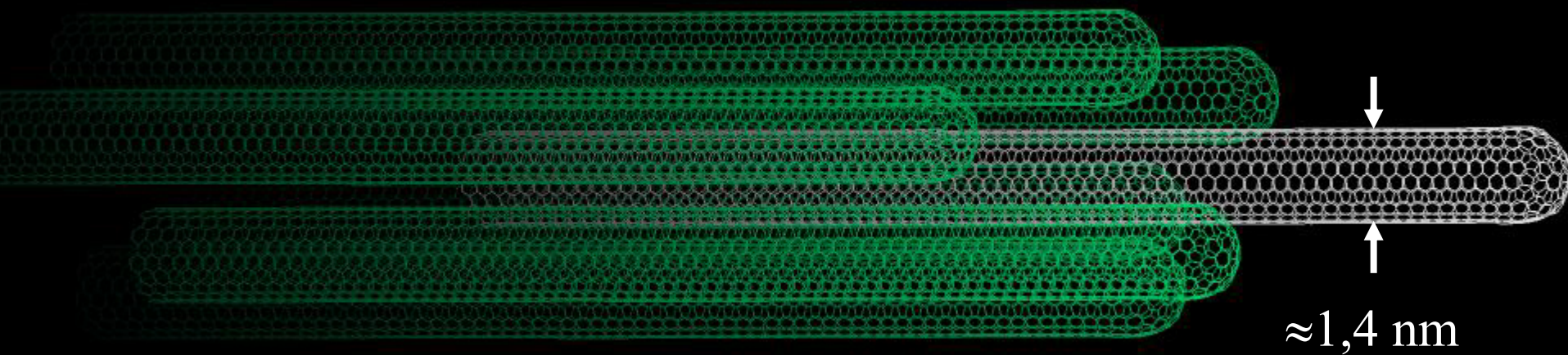
## egyfalú nanocsövek előállítása

Thess et al., Science 273, 483 (1996)





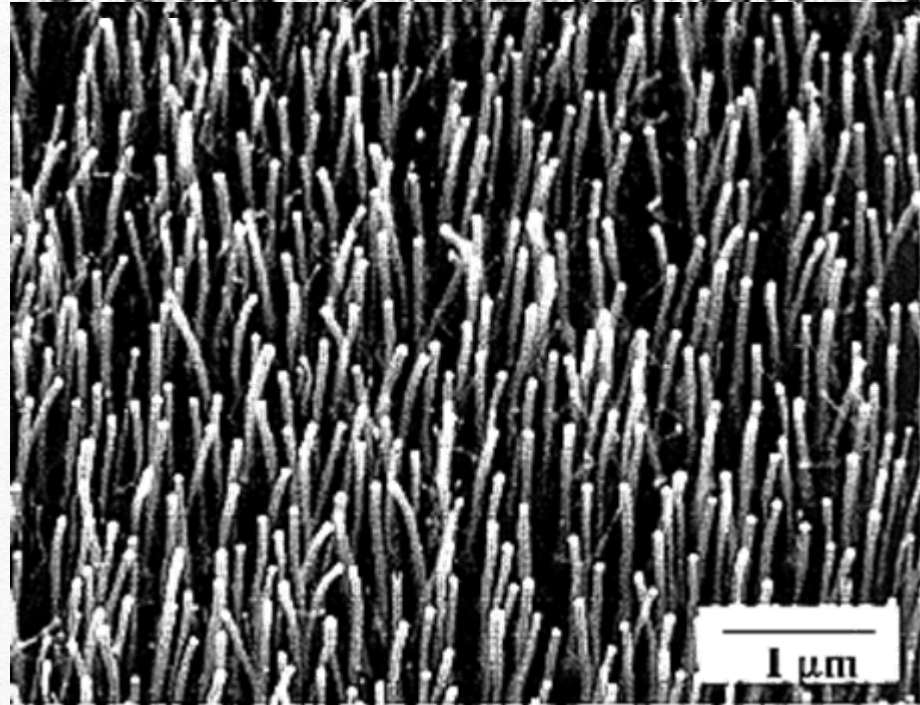
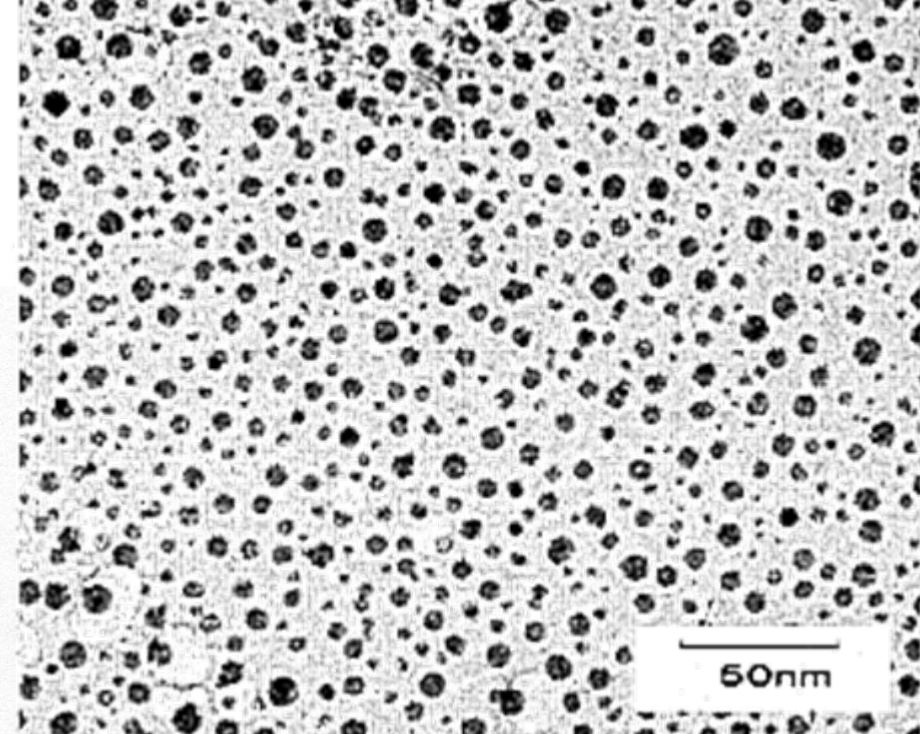
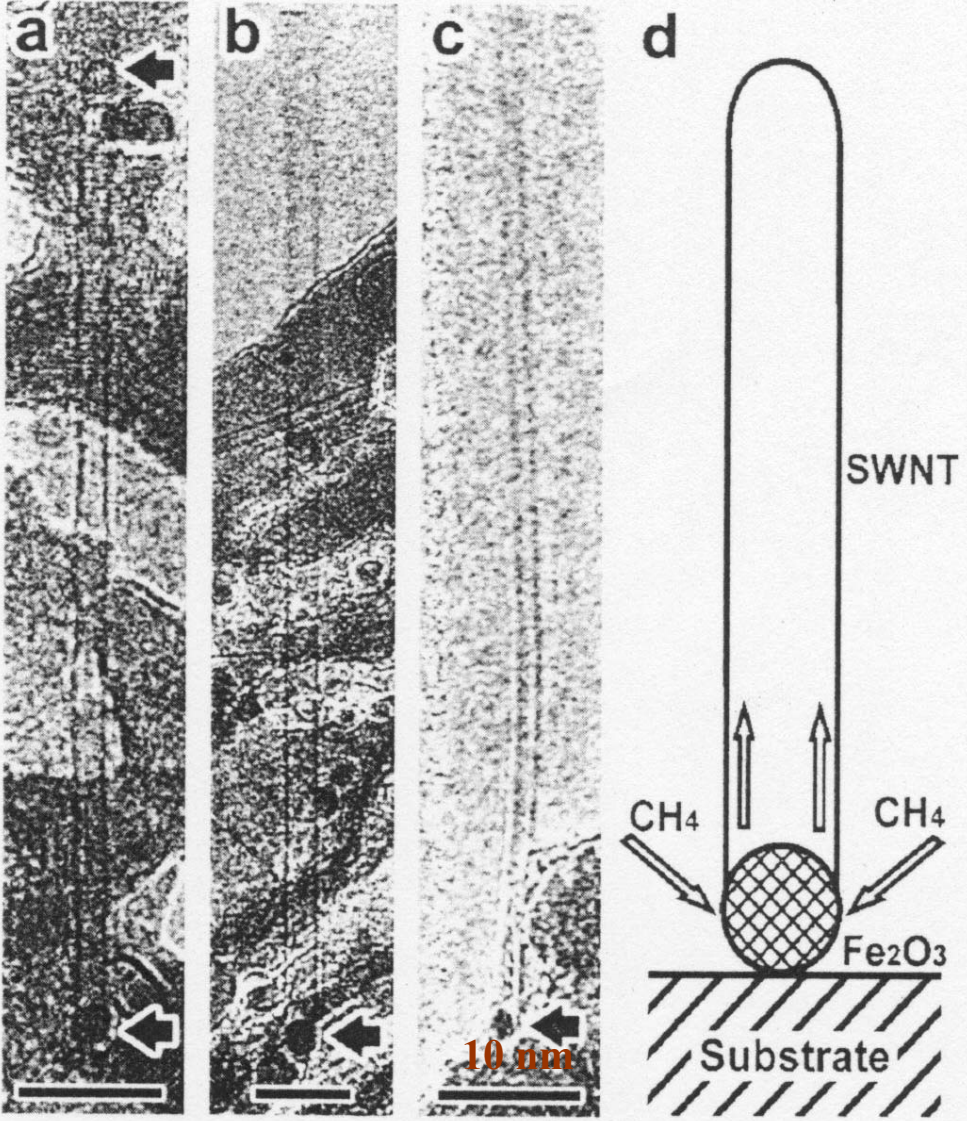


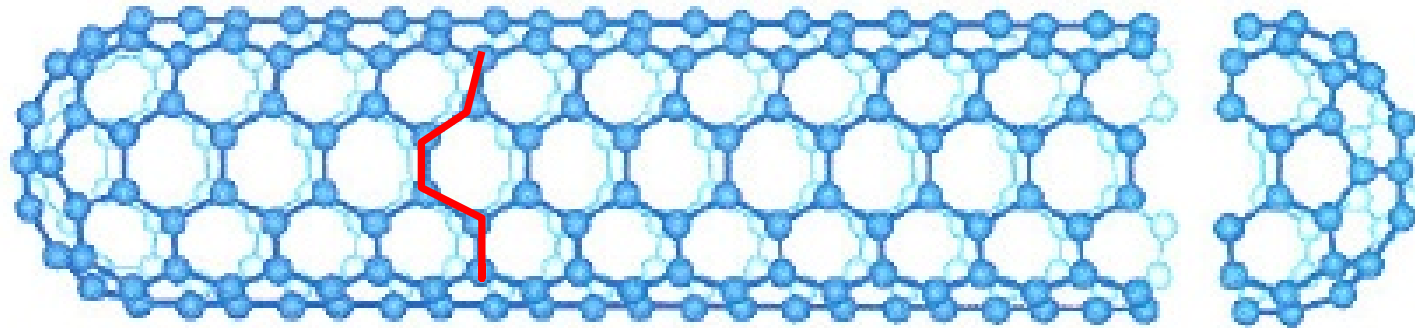




# CVD módszerrel történő előállítás

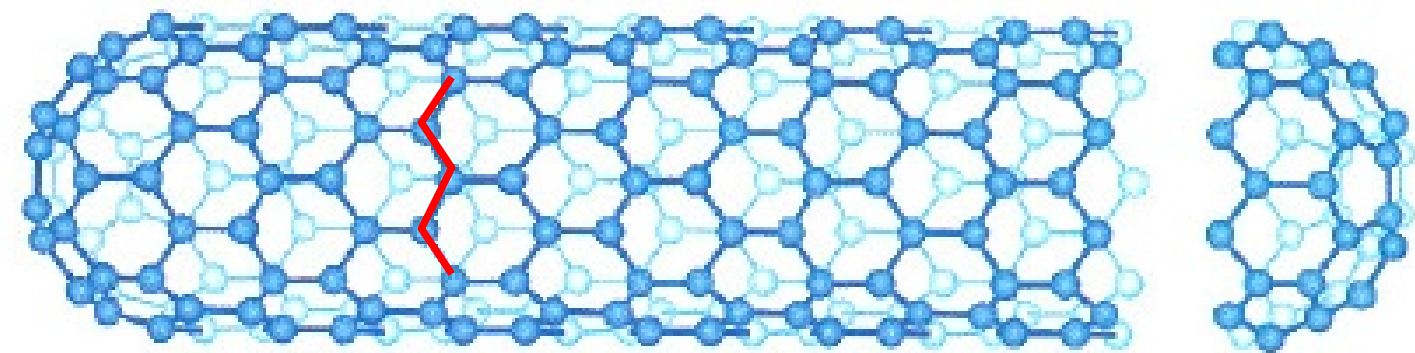
(chemical vapor deposition)





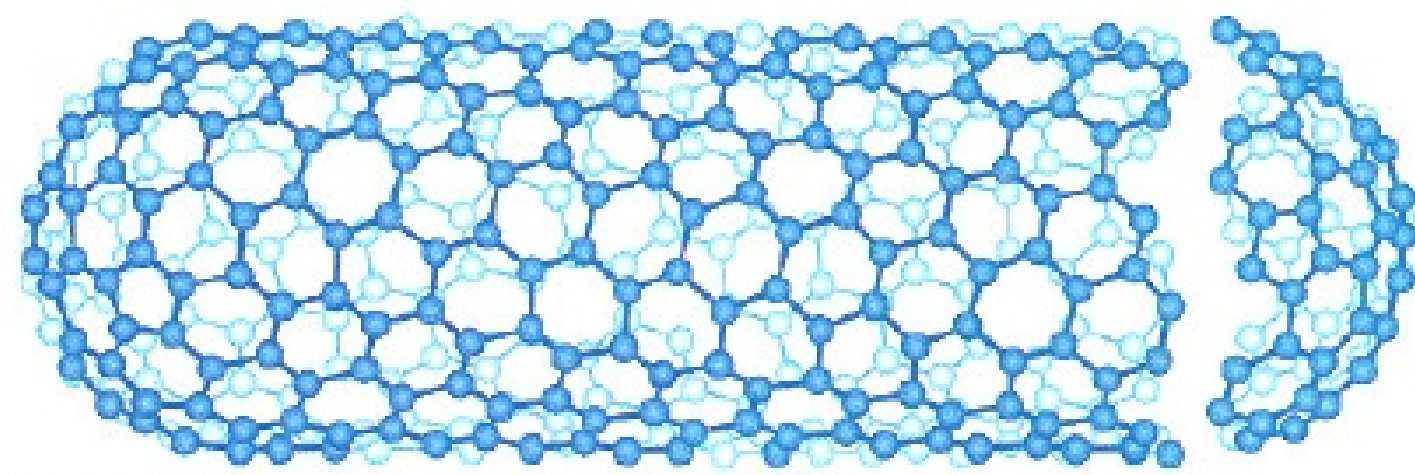
karosszék  
(armchair)

$(n,m) = (5,5)$



cikk-cakk  
(zig-zag)

$(n,m) = (9,0)$



királis  
(chiral)

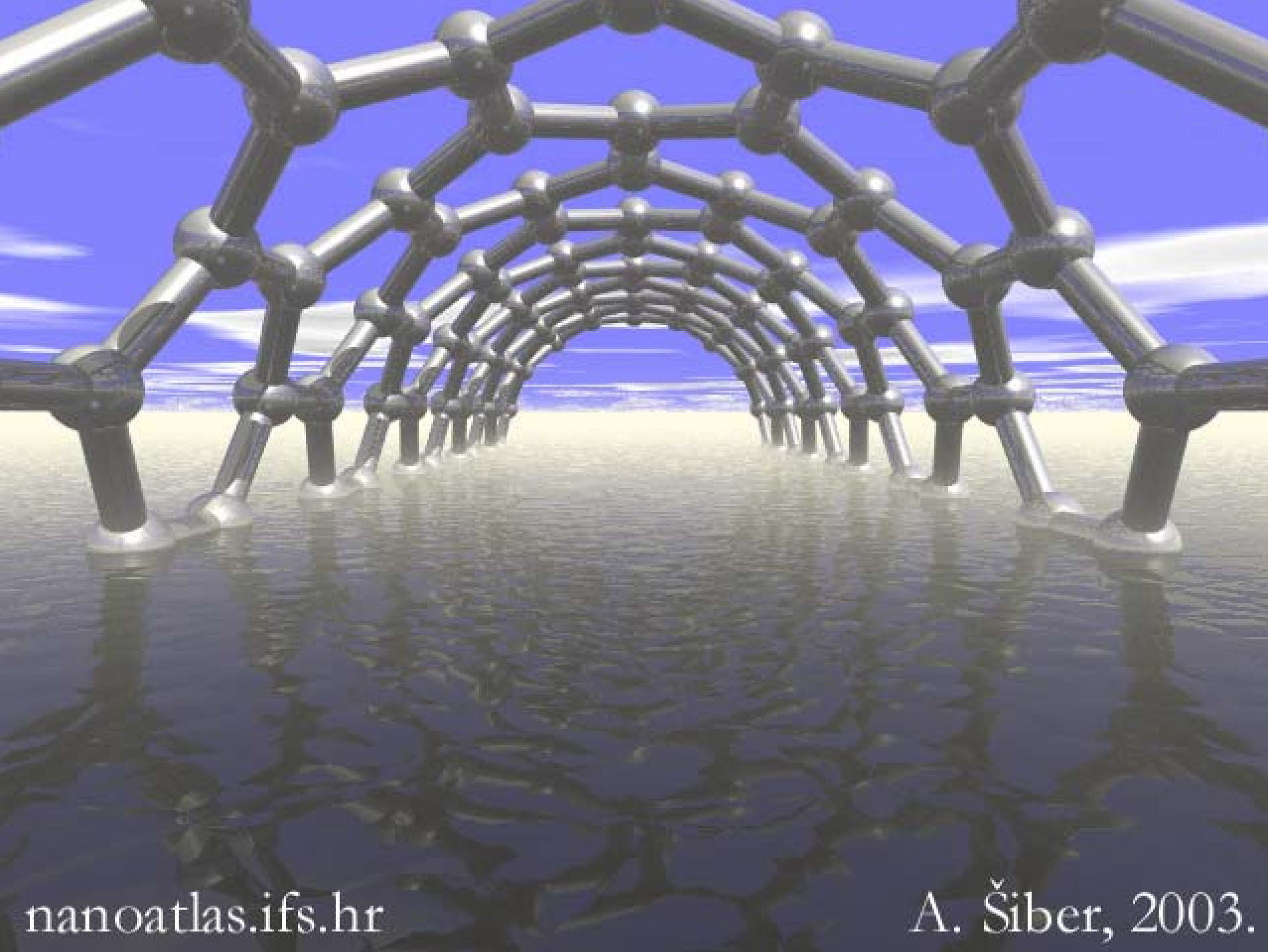
$(n,m) = (10,5)$

A. Šiber, 2003.



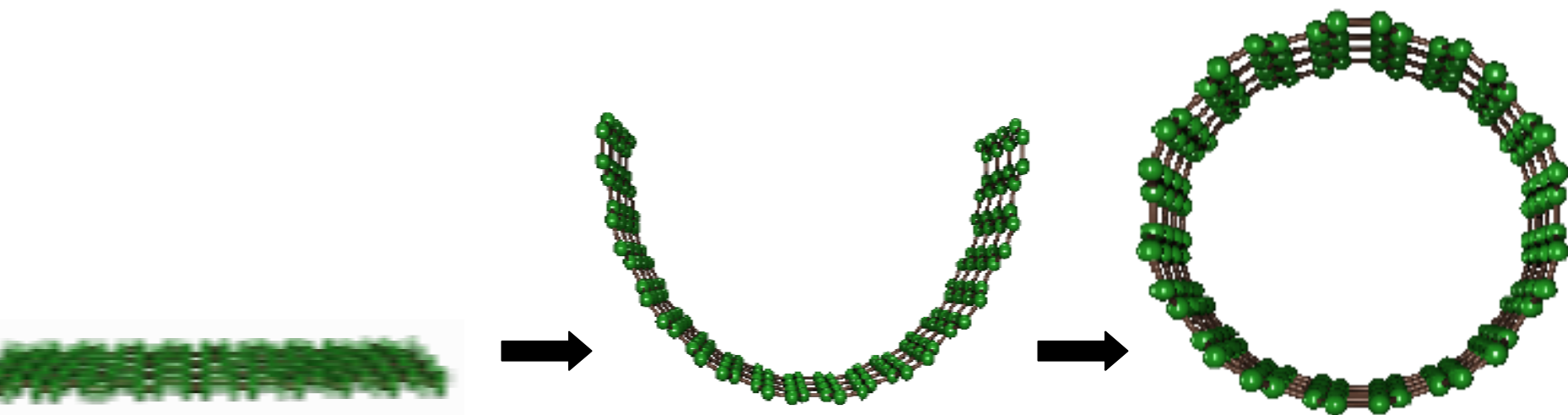
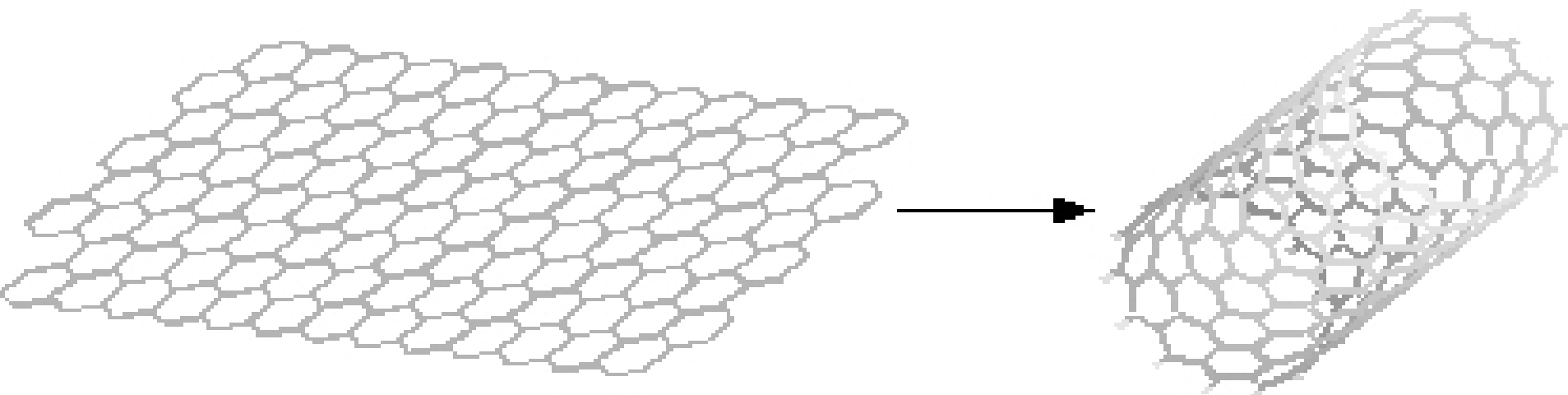
[nanoatlas.ifs.hr](http://nanoatlas.ifs.hr)

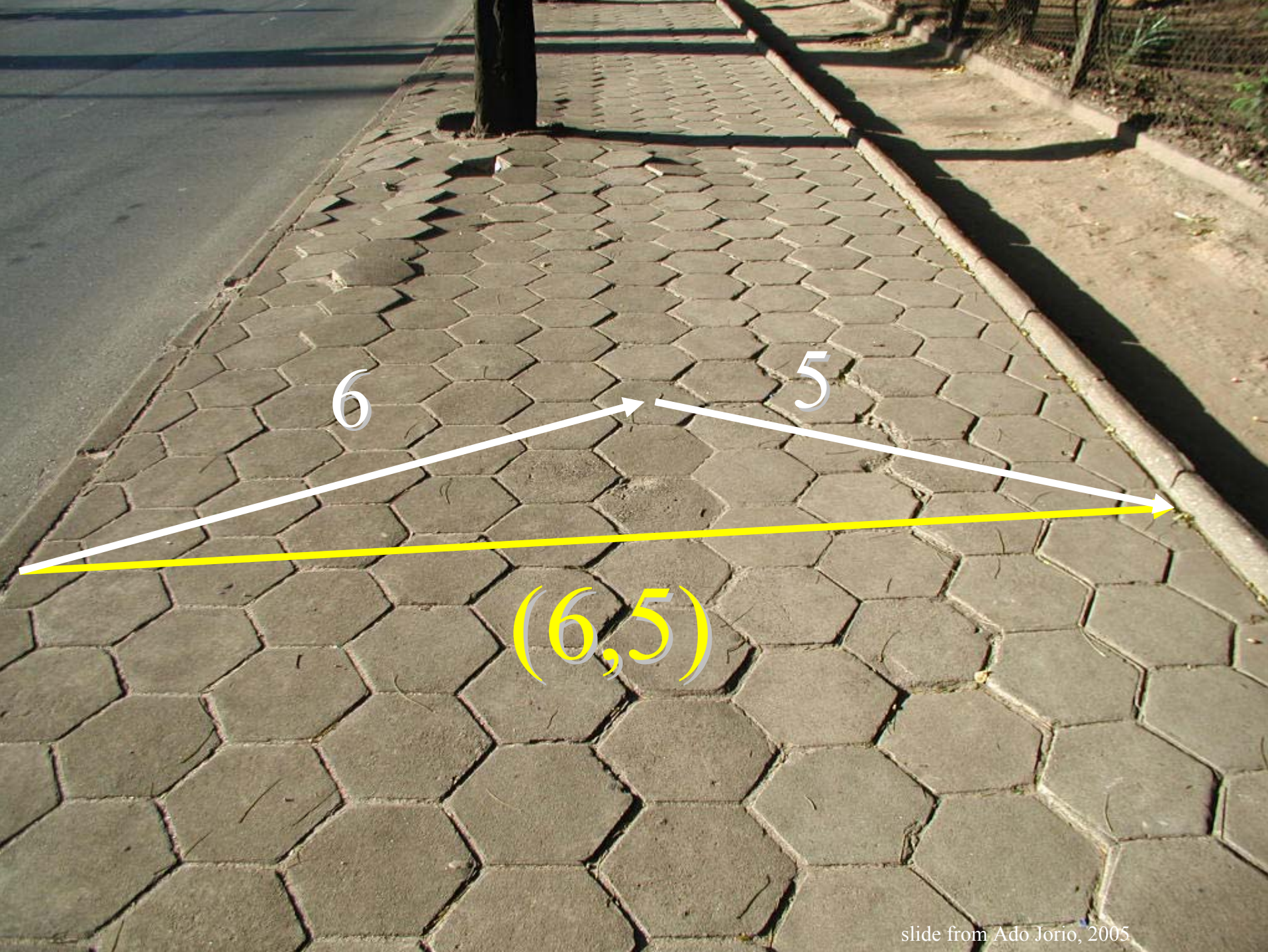






# Szén nanocső (elvi!) származtatása grafit sík (grafén) feltekeréséből



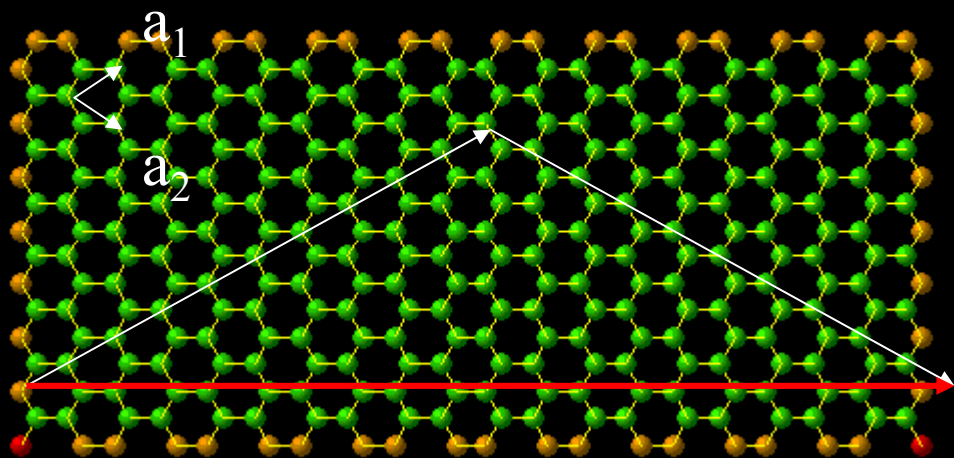


6

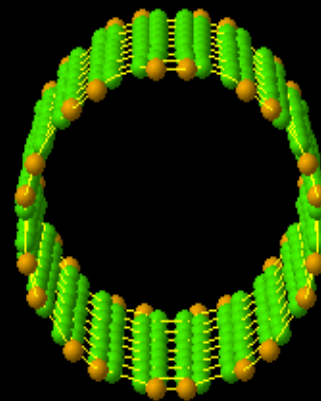
5

(6,5)





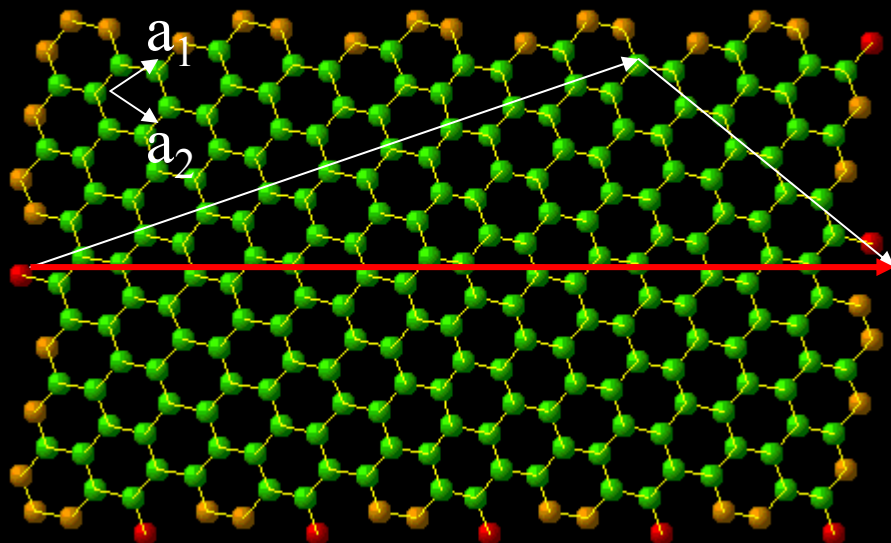
(10,10)



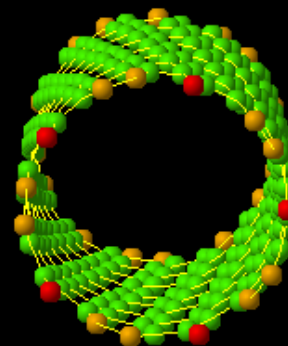
akirális

(karosszék)

$C_h$  kiralitás („feltekerési”) vektor =  $n \cdot a_1 + m \cdot a_2$



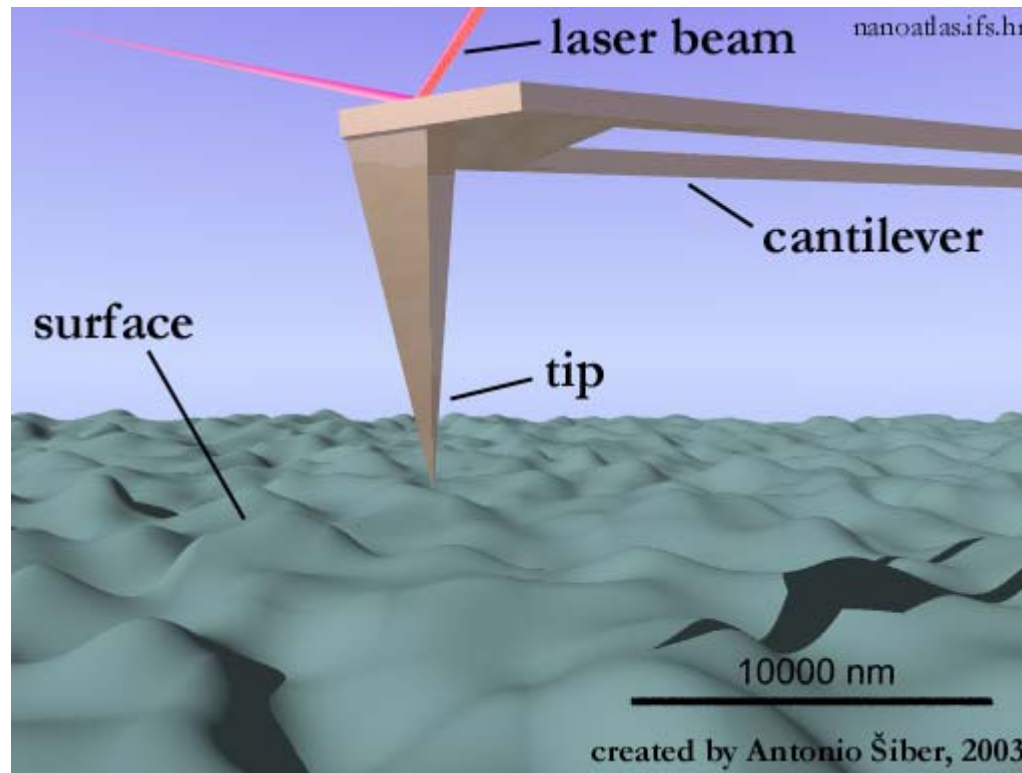
(10,5)



királis

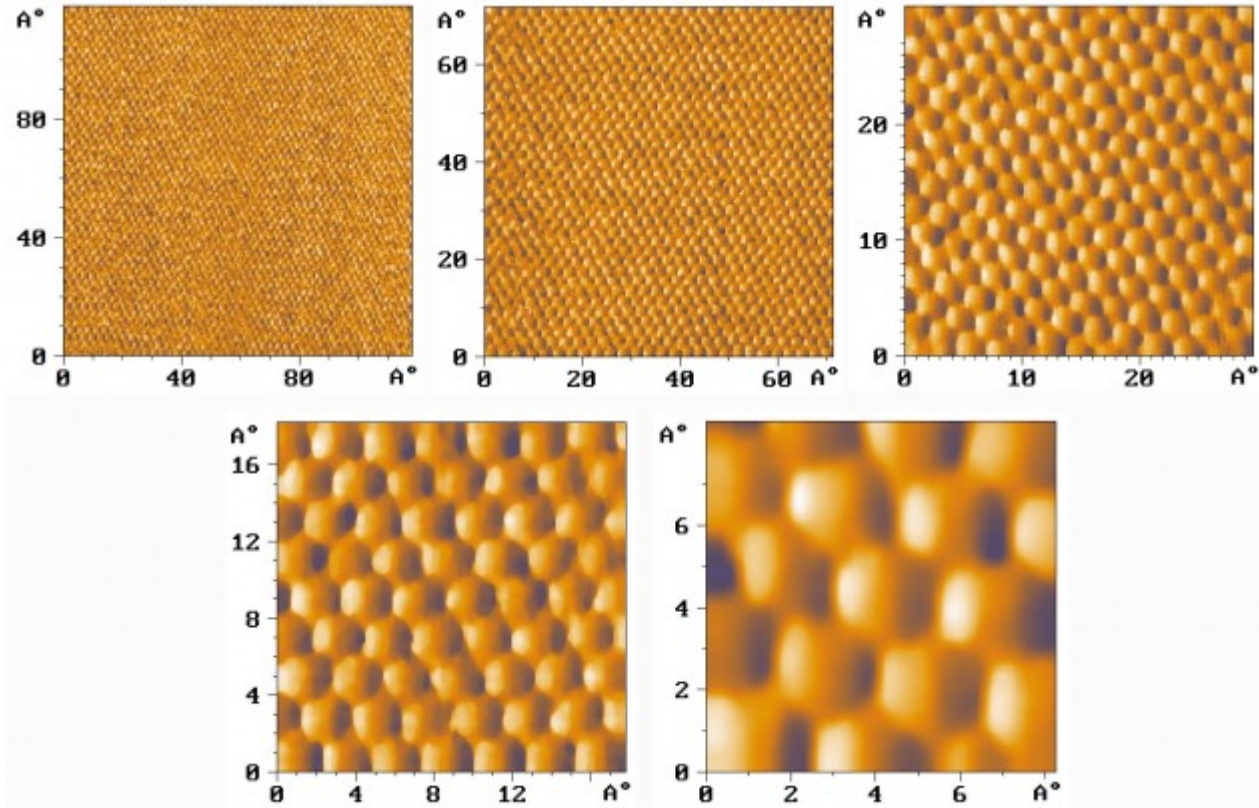
# PÁSZTÁZÓ ERŐ MIKROSZKÓP

## Atomic Force Microscope



# AFM

# GRAFIT

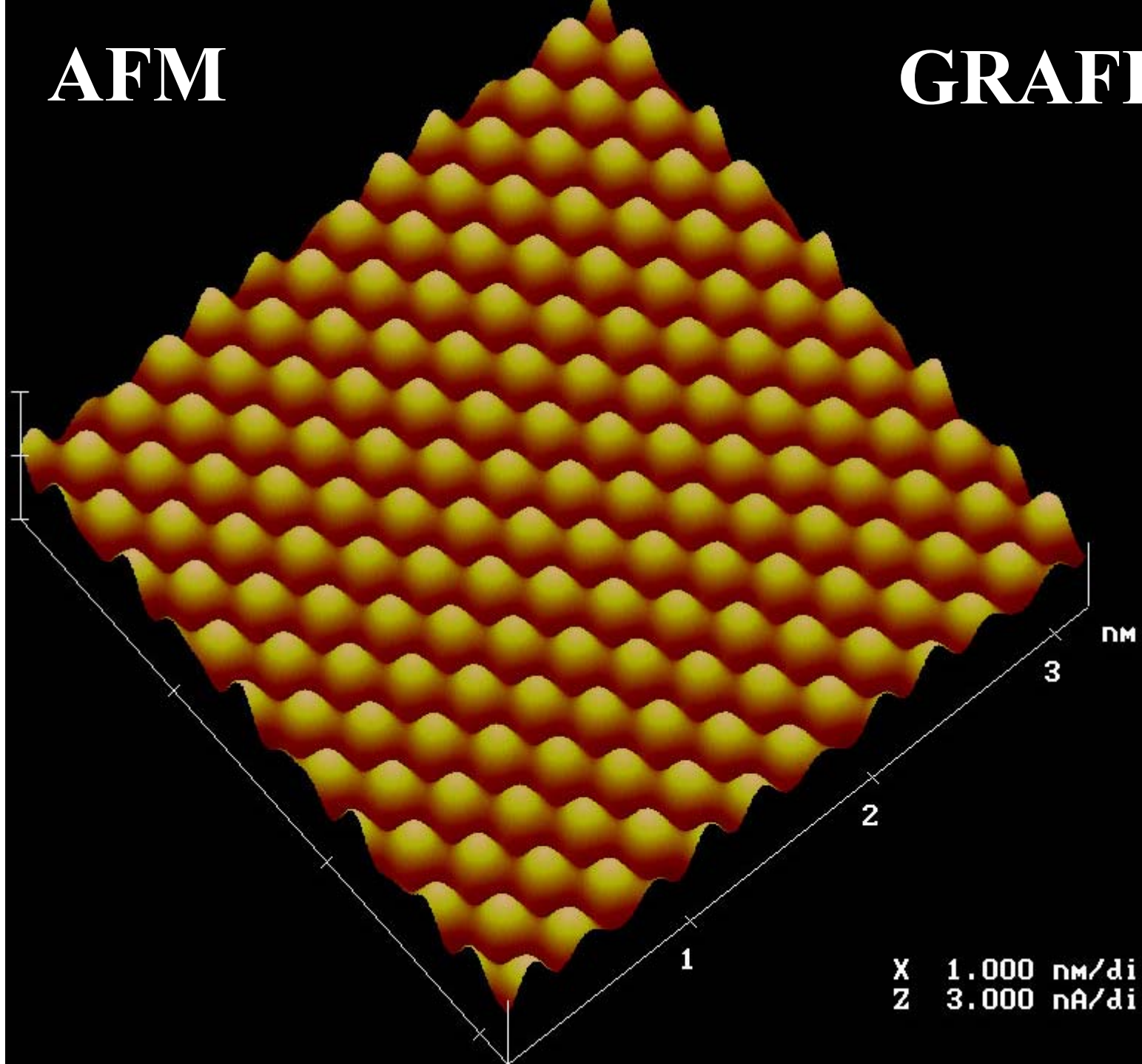


$$1 \text{ \AA} = 0,1 \text{ nm} = 10^{-10} \text{ m} = 0,000 \ 000 \ 000 \ 1 \text{ m}$$



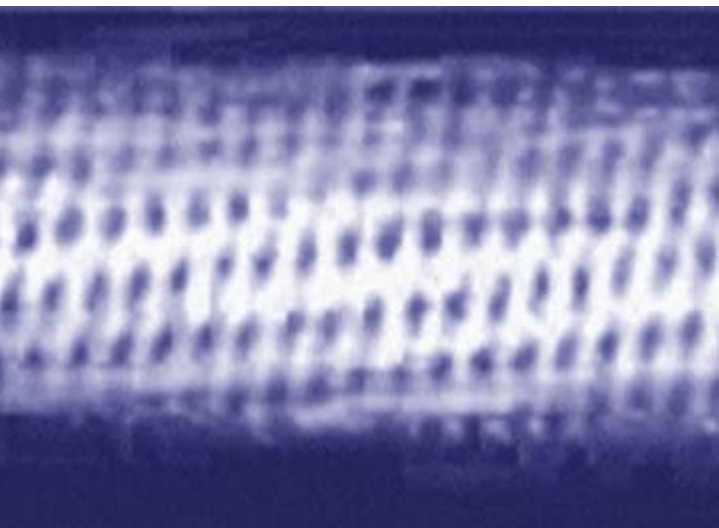
**AFM**

**GRAFIT**



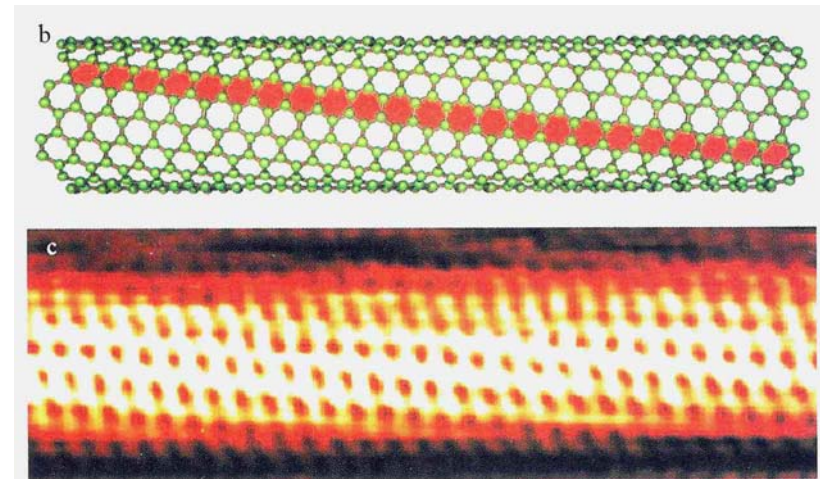
X 1.000 nm/div  
Z 3.000 nA/div

# Pásztázó alagútmikroszkóp (STM) felvételek egyfalú szén nanocsőről

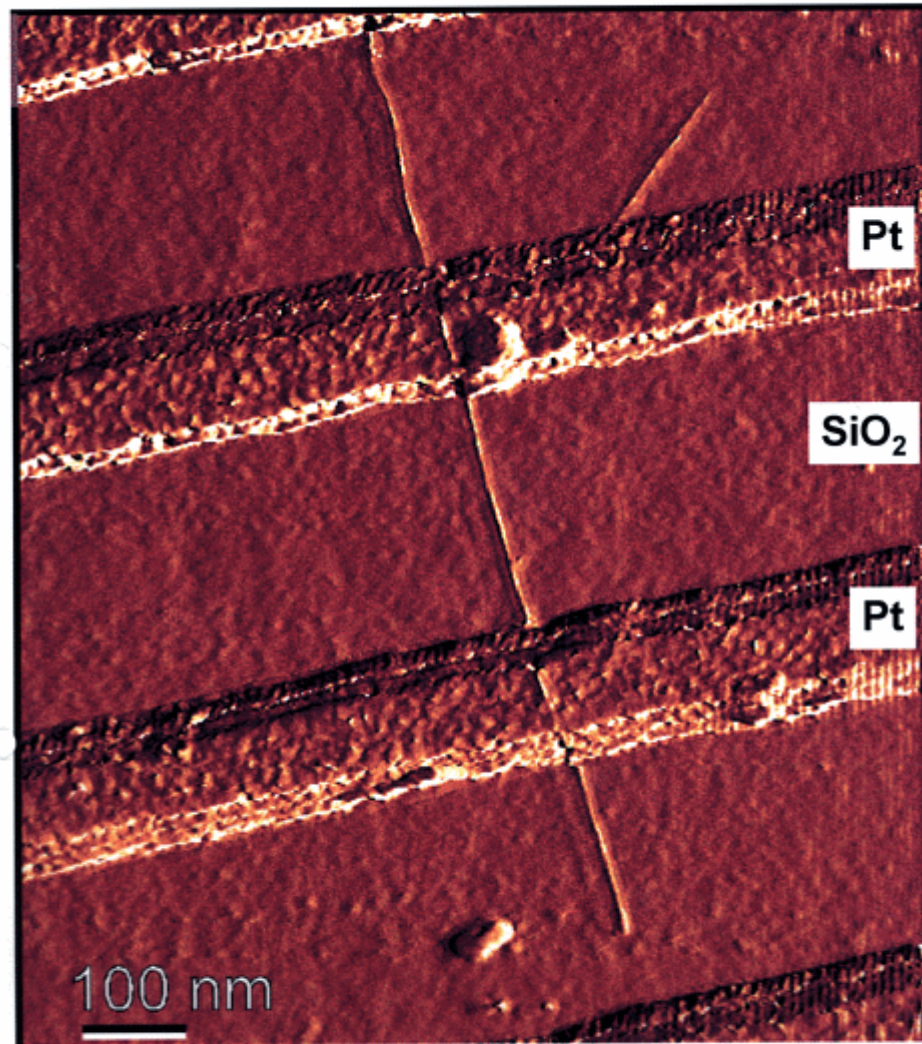


↑  
1,4 nm  
↓

(11,7)

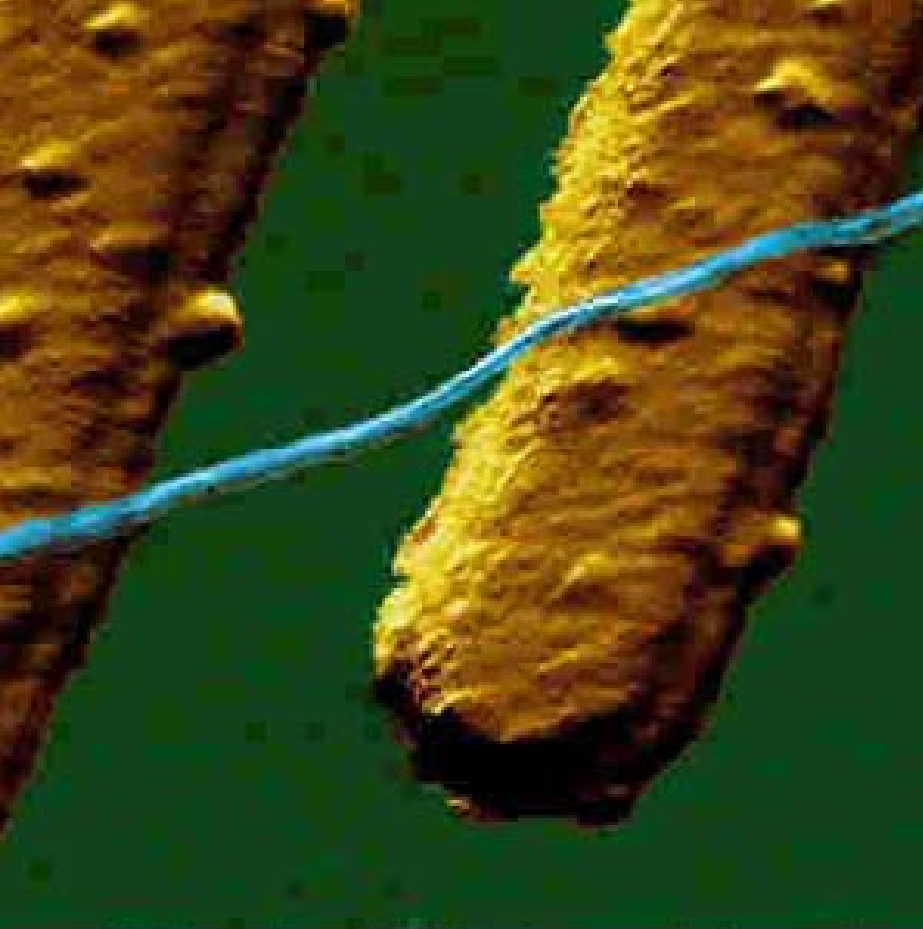


# Nanocső lerakása szuszpenzióból forgótárcsás (spin-coating) technikával

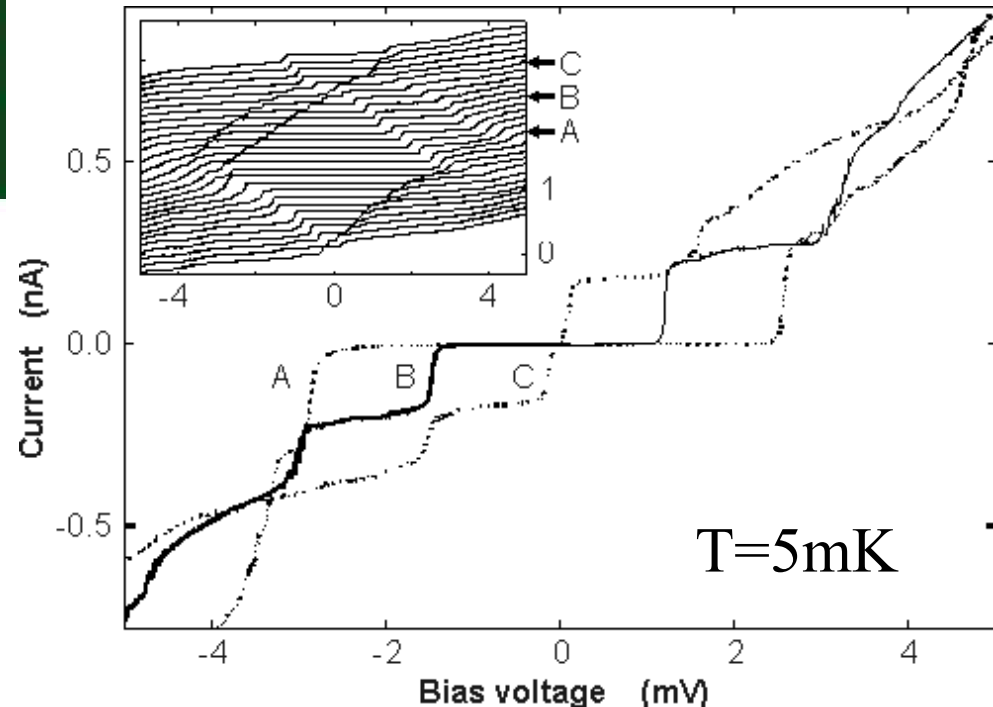
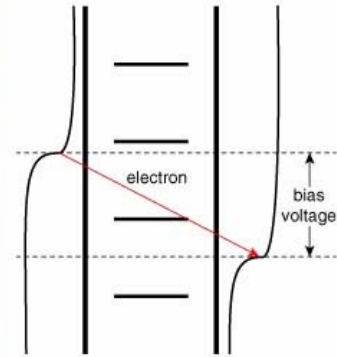
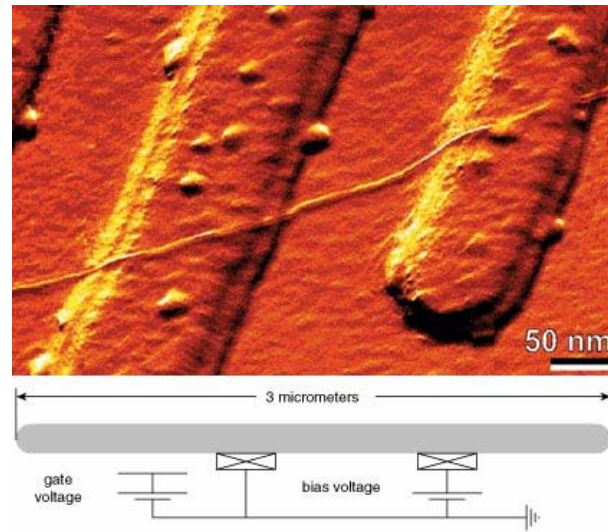
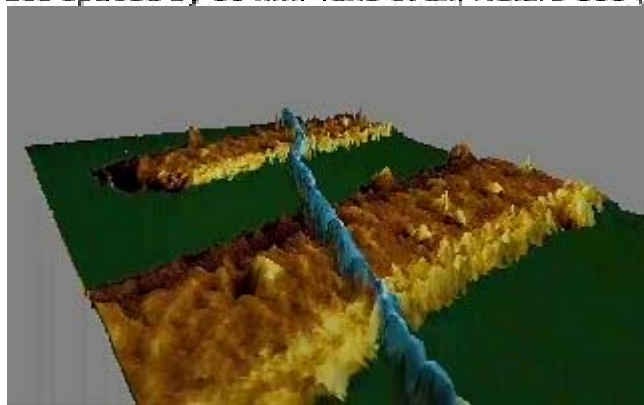


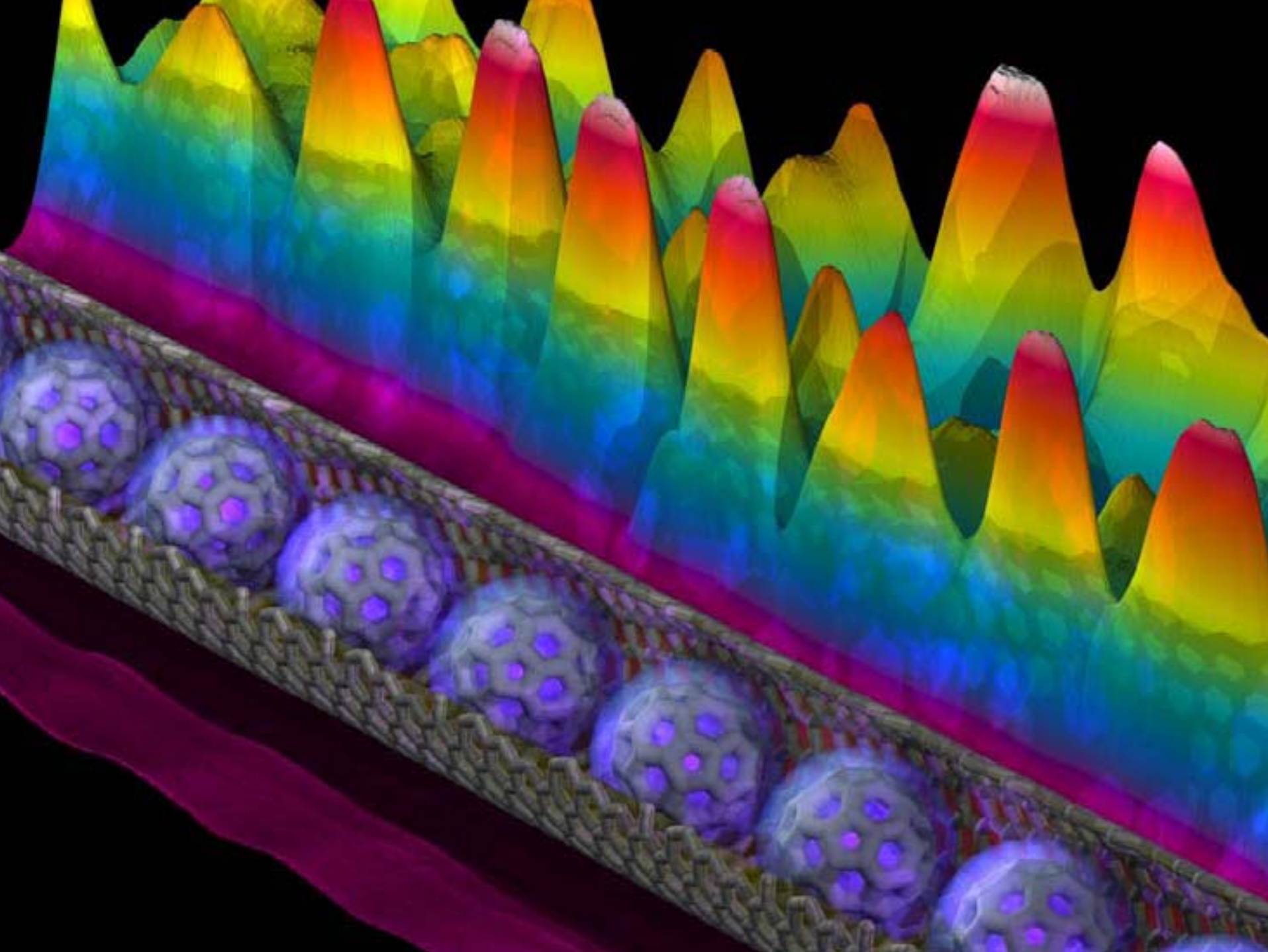
Results in **individual** tubes on electrodes !





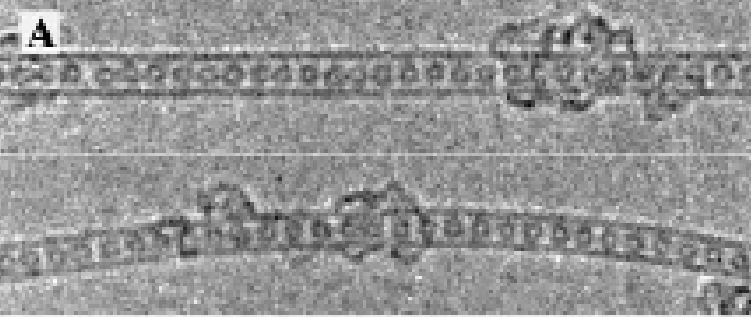
AFM image of an individual carbon nanotube between Pt electrodes spaced by 50 nm. Tans et al., *Nature* 386 (1997) 474.



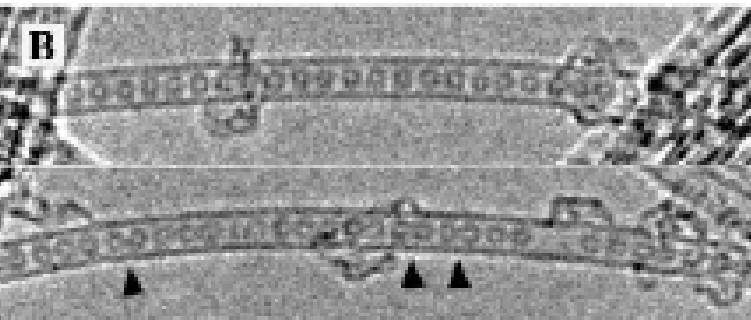


013691

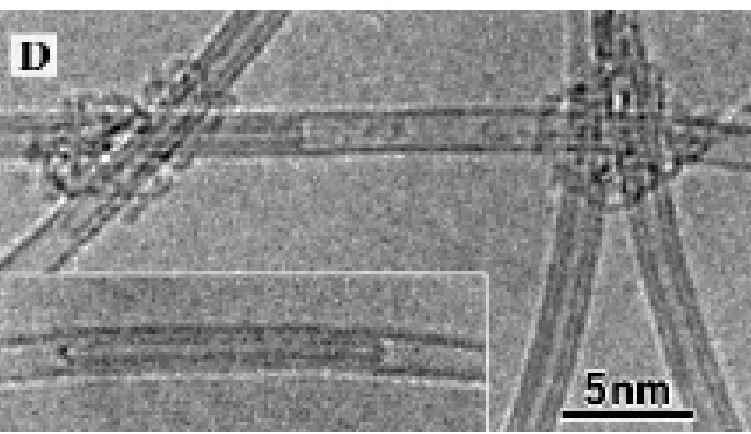
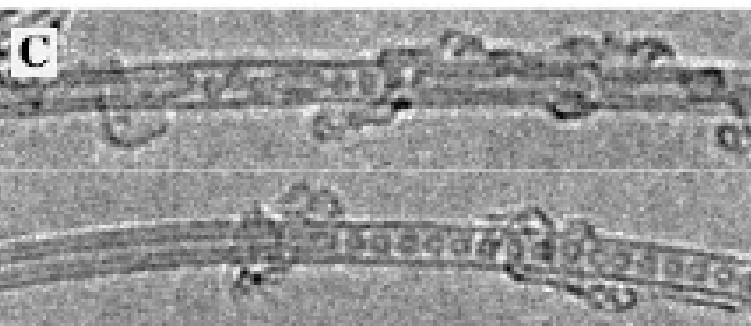




„borsó” = C60 @ nanocső



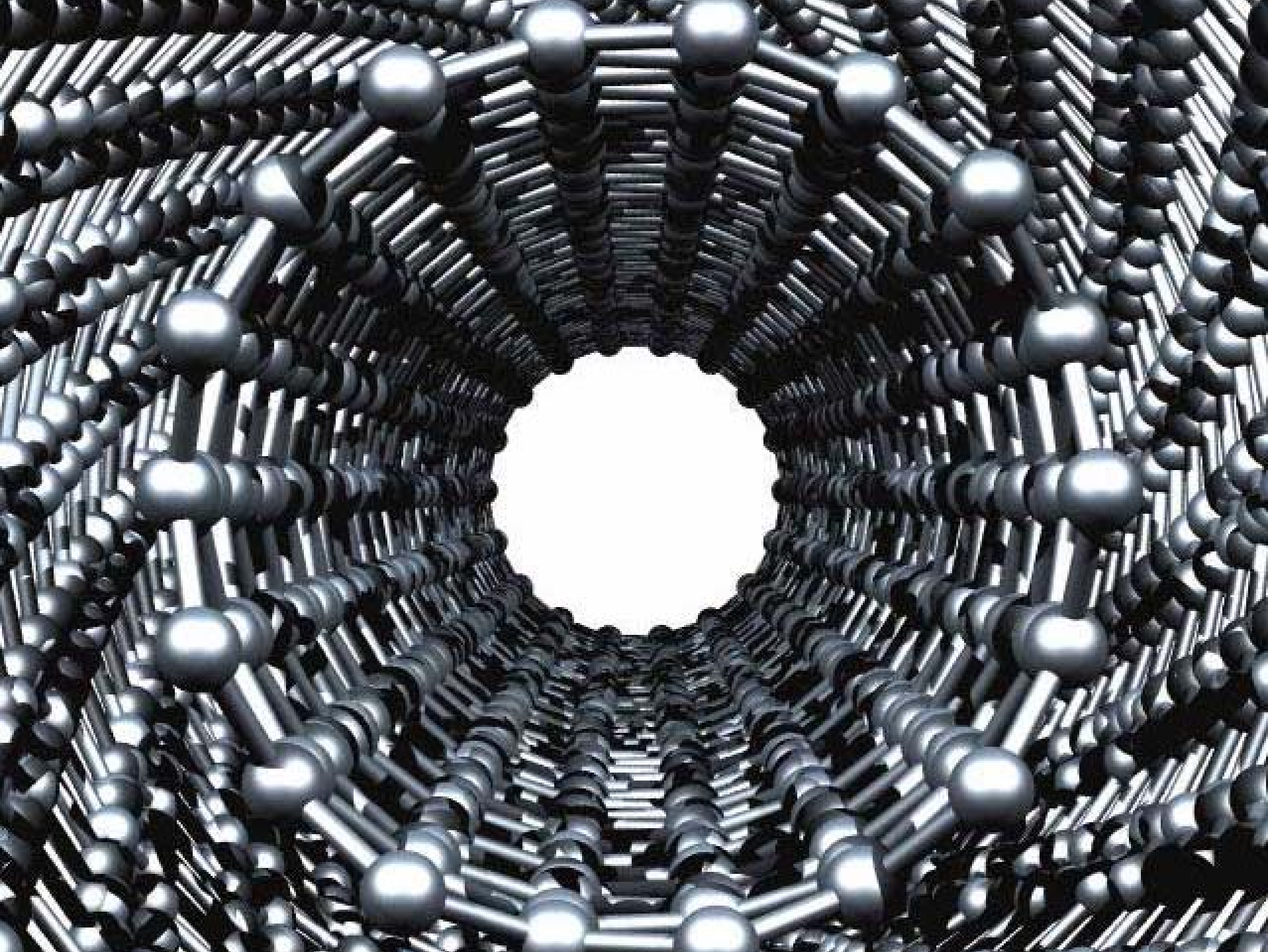
hőkezelés



duplafalú szén nanocső

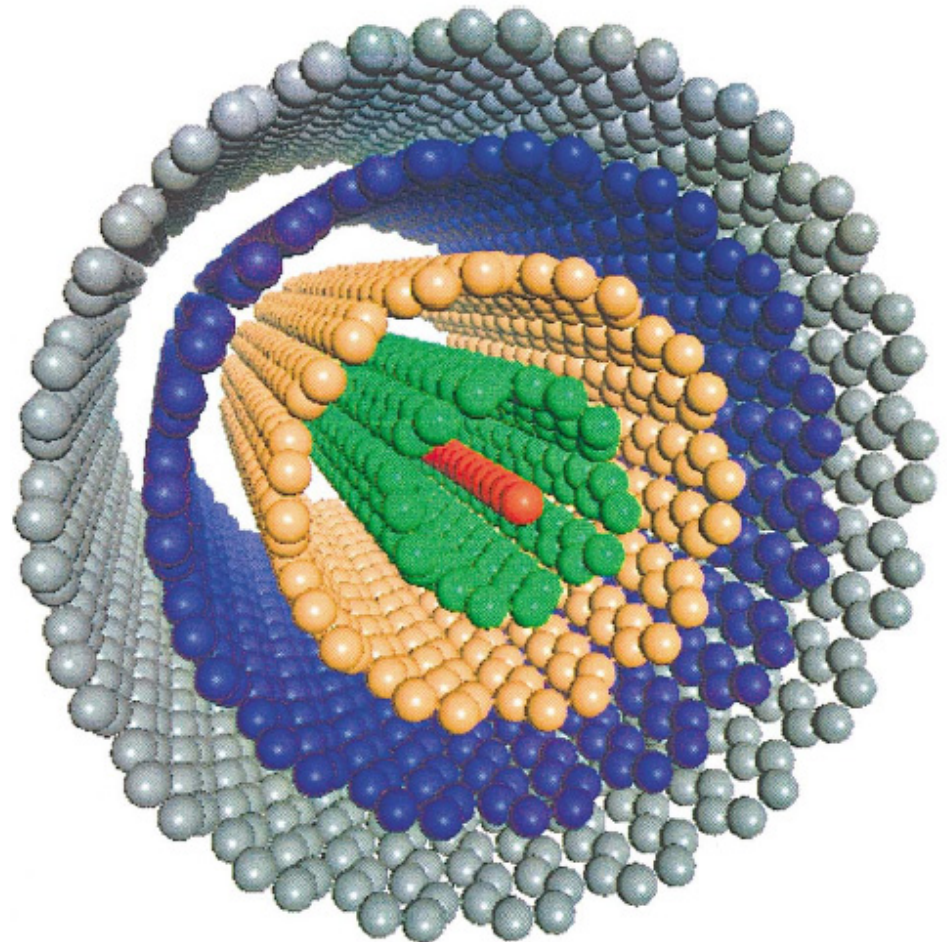
a belső cső átmérője  $\approx 0.5-0.9$  nm

S.Bandow et al., CPL 337, 48 (2001)



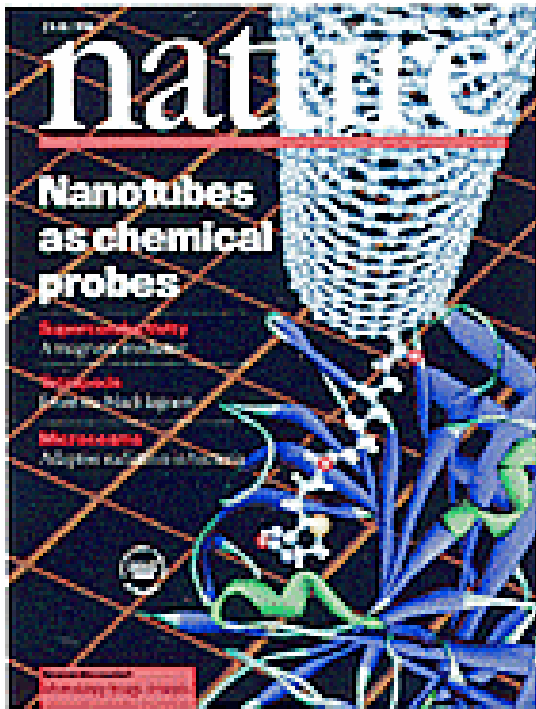
# A „legkisebb belső átmérőjű cső” = lineáris szénlánc

félvezető      félvezető  
↓                      ↓  
szénlánc @ (7,1)  
↑  
fémes! 🤔






# Alkalmazási lehetőségek



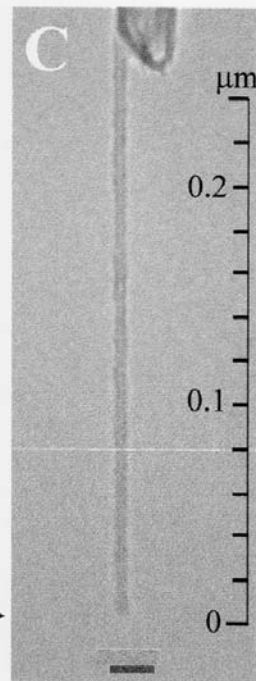
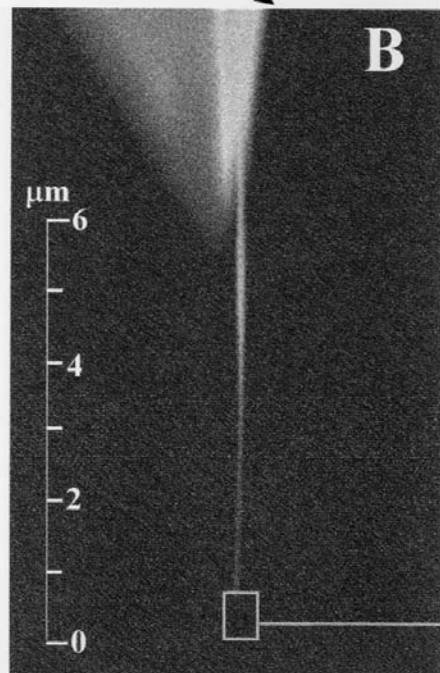
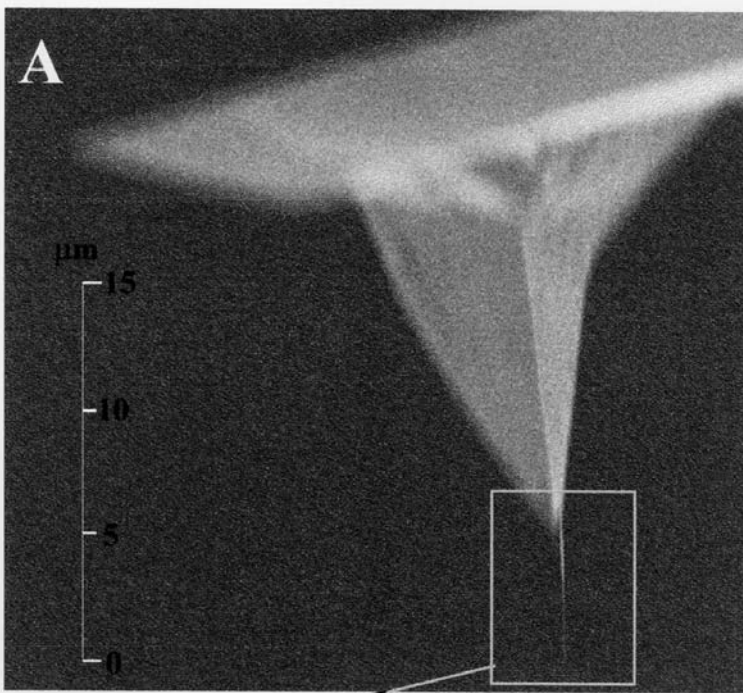
**kémiai szenzorok**  
(funkcionalizálás)



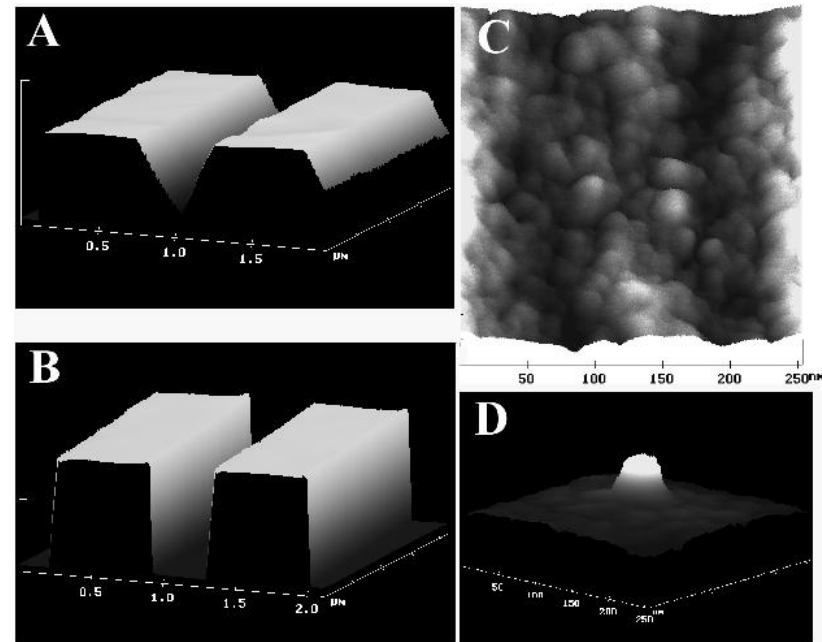
**nanoelektronika:**   
n-m osztható 3-mal → fémes  
a többi félvezető → nano-IC



**különleges mechanikai tulajdonságok:**  
erős, könnyű, stabil, flexibilis



AFM-tű



# Field Emission Applications



E-gun for SEM



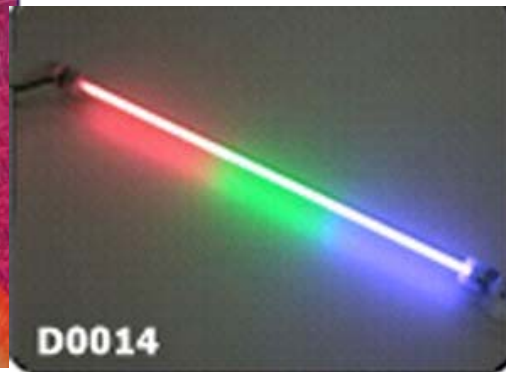
Microwave Amplifier



Displays



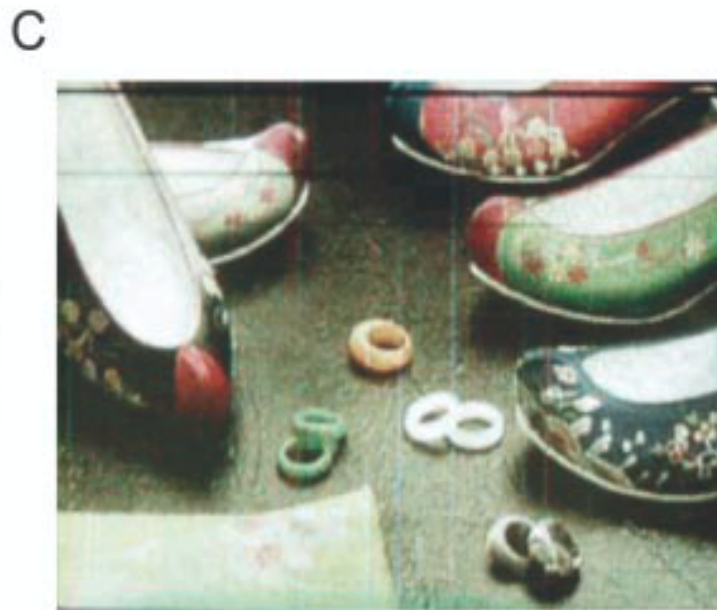
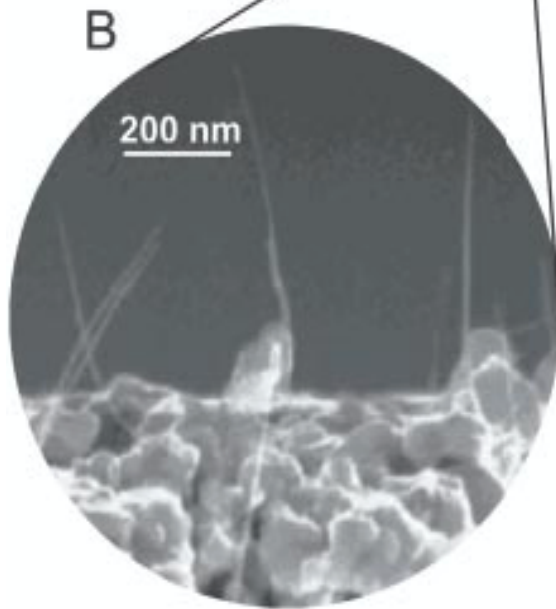
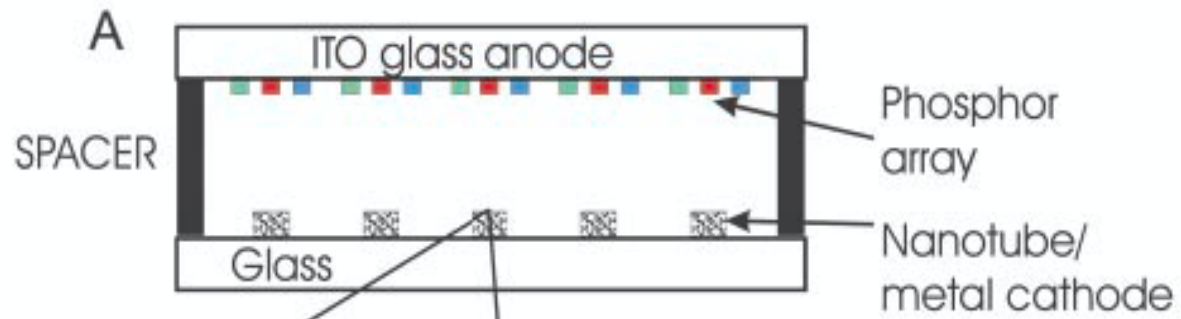
X-ray sources



lamps



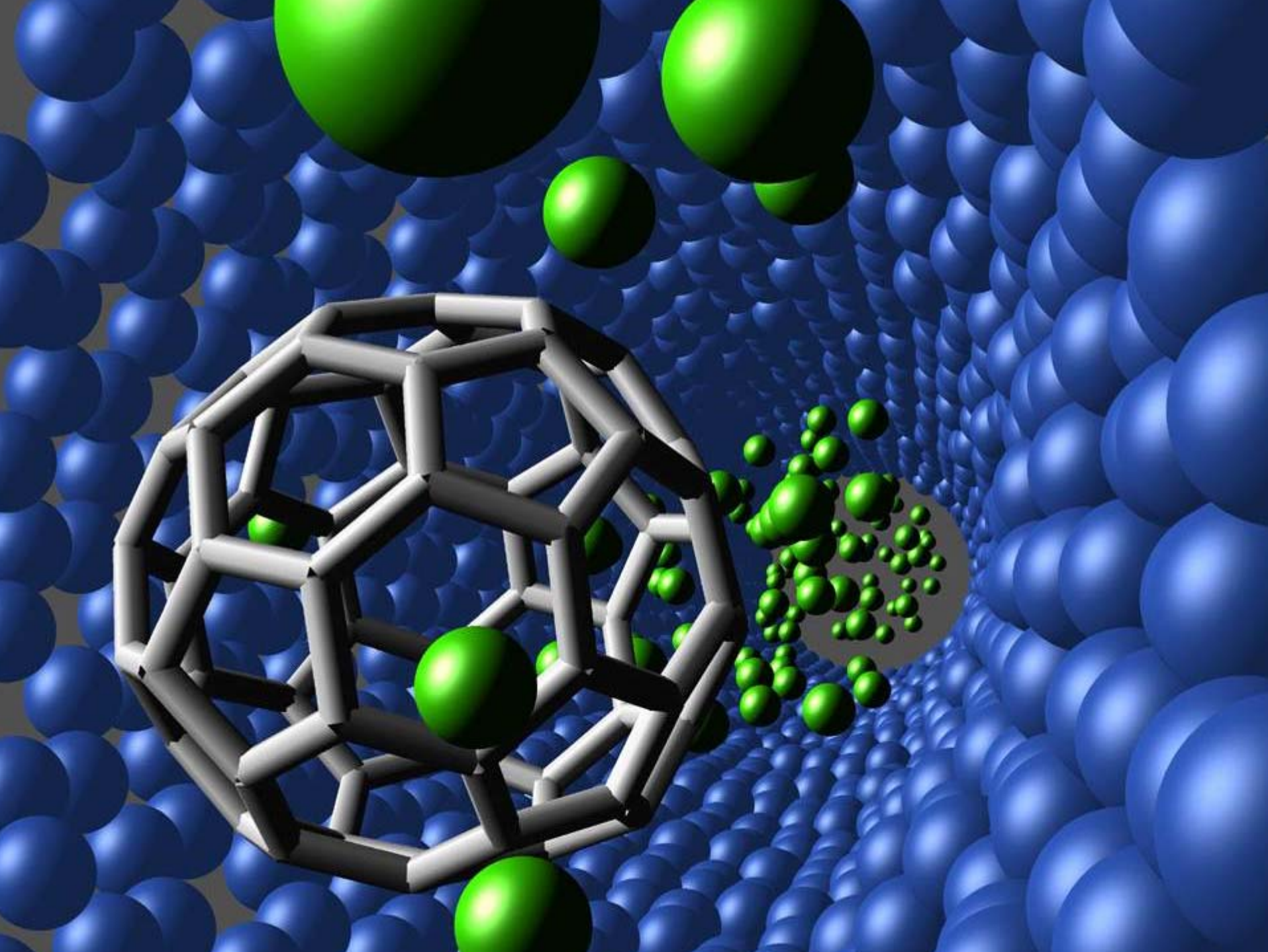


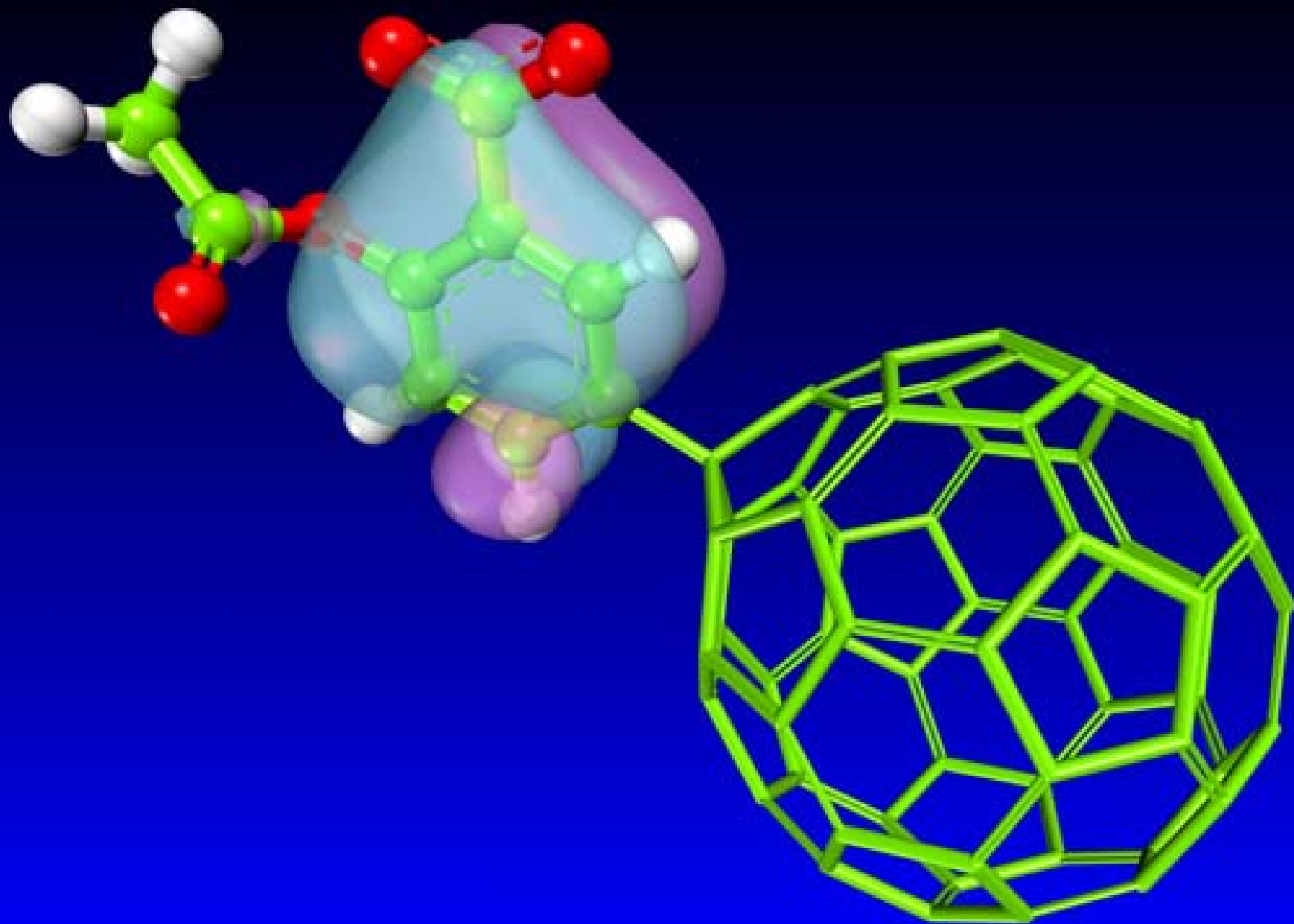


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Carbon Nanotubes—the Route Toward Applications

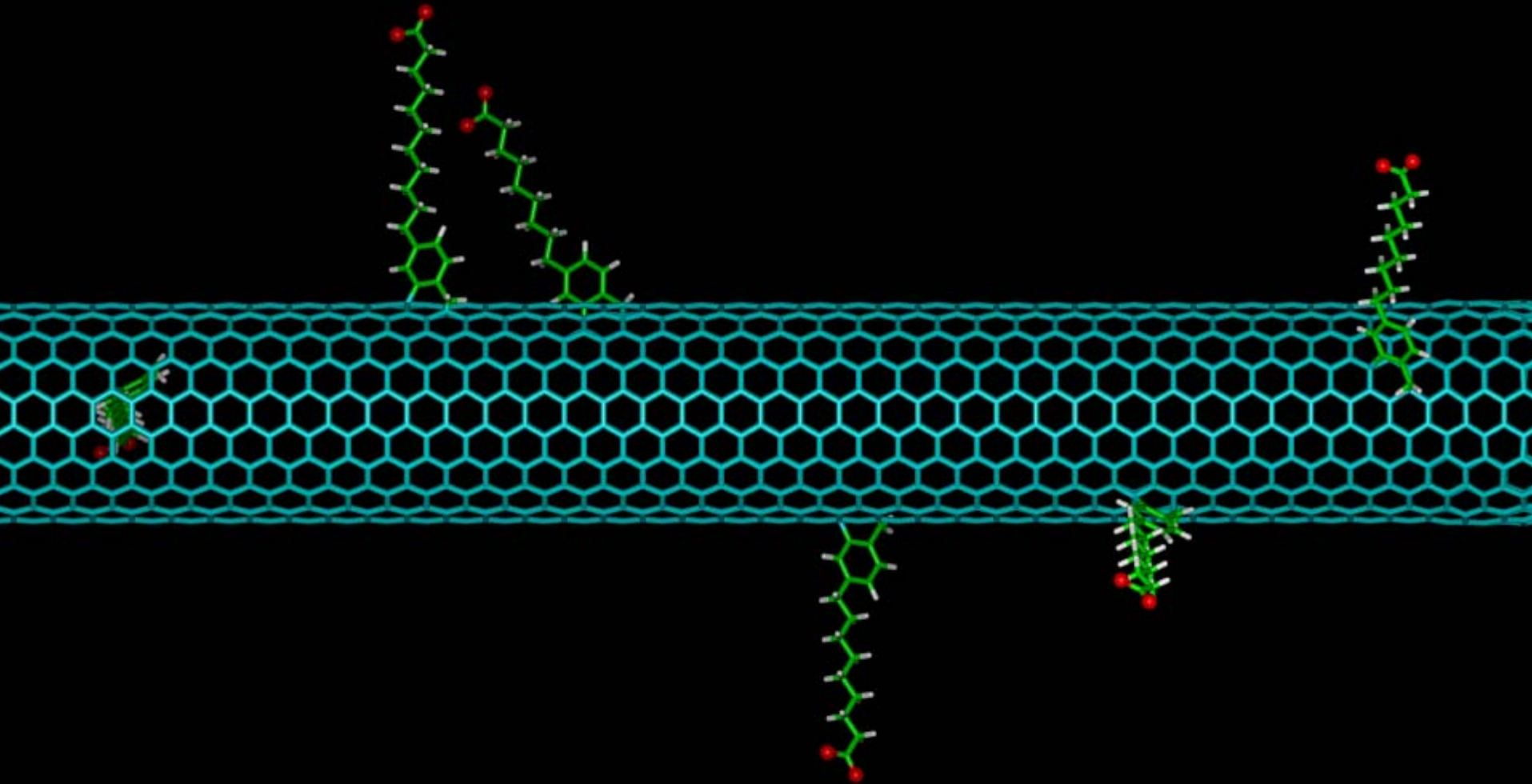
Ray H. Baughman, Anvar A. Zakhidov, Walt A. de Heer

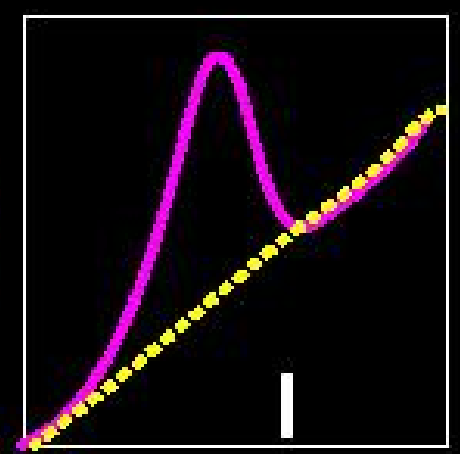
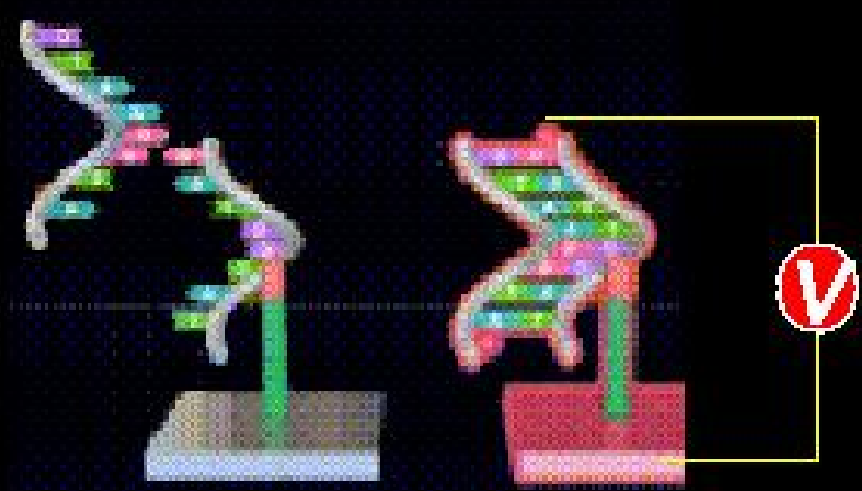
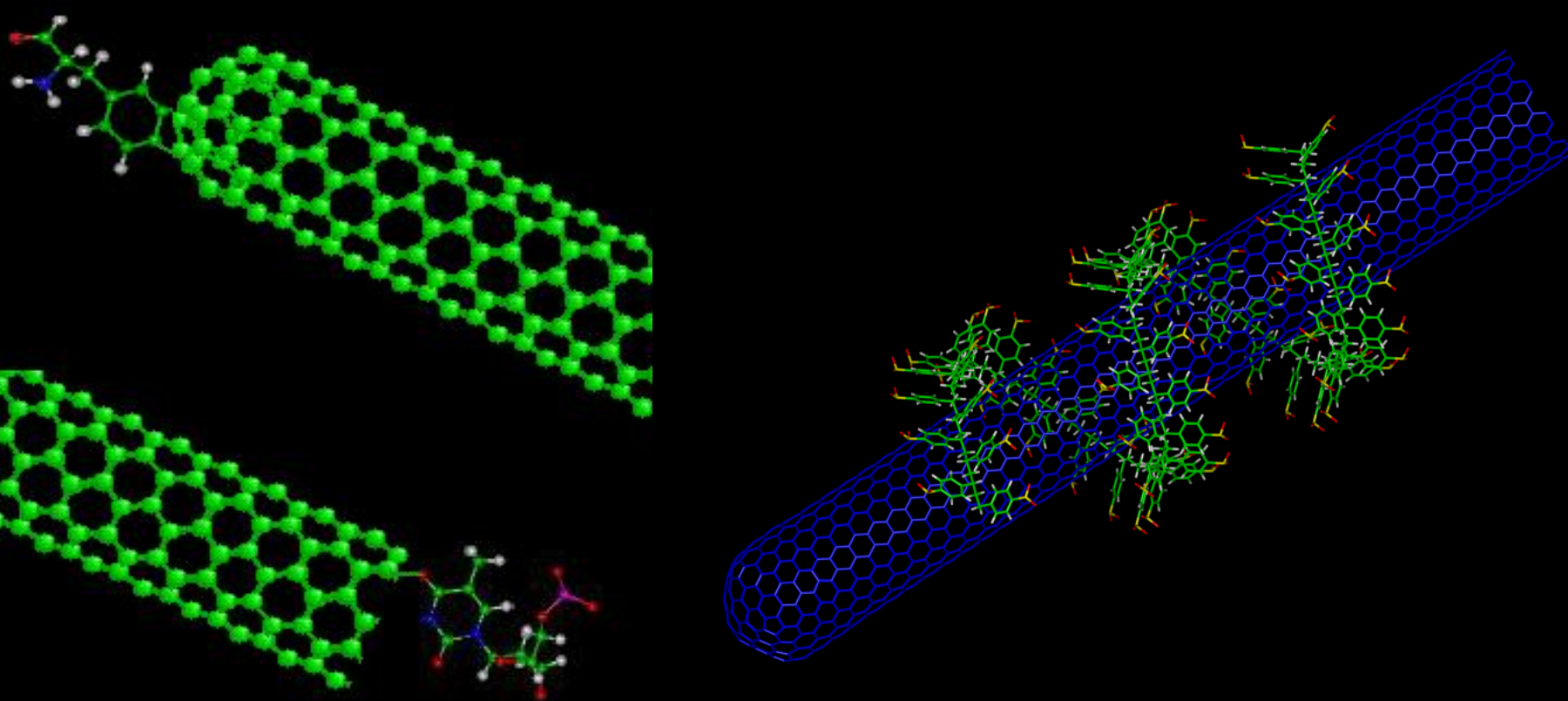




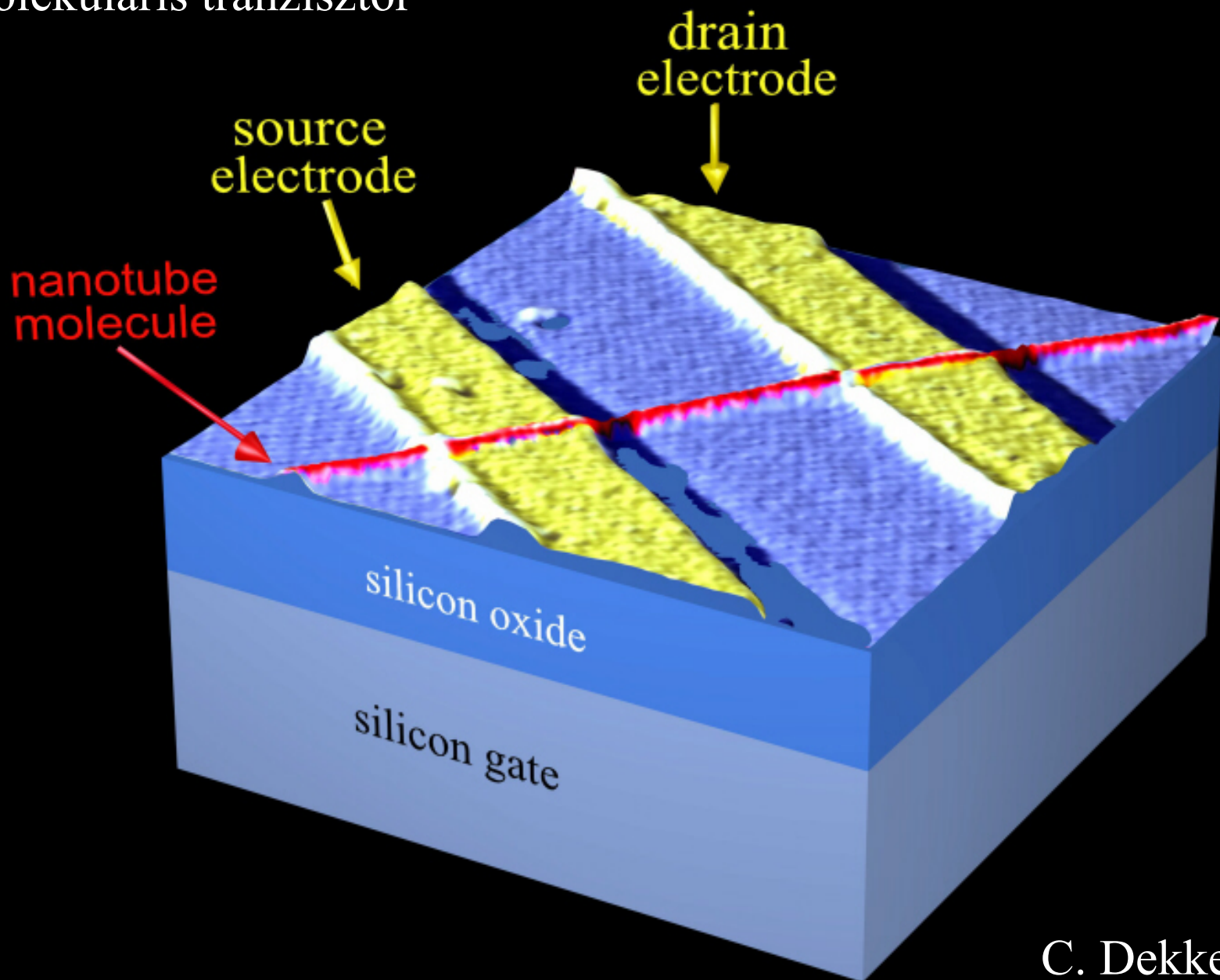


funkcionalizálás





# molekuláris tranzisztor





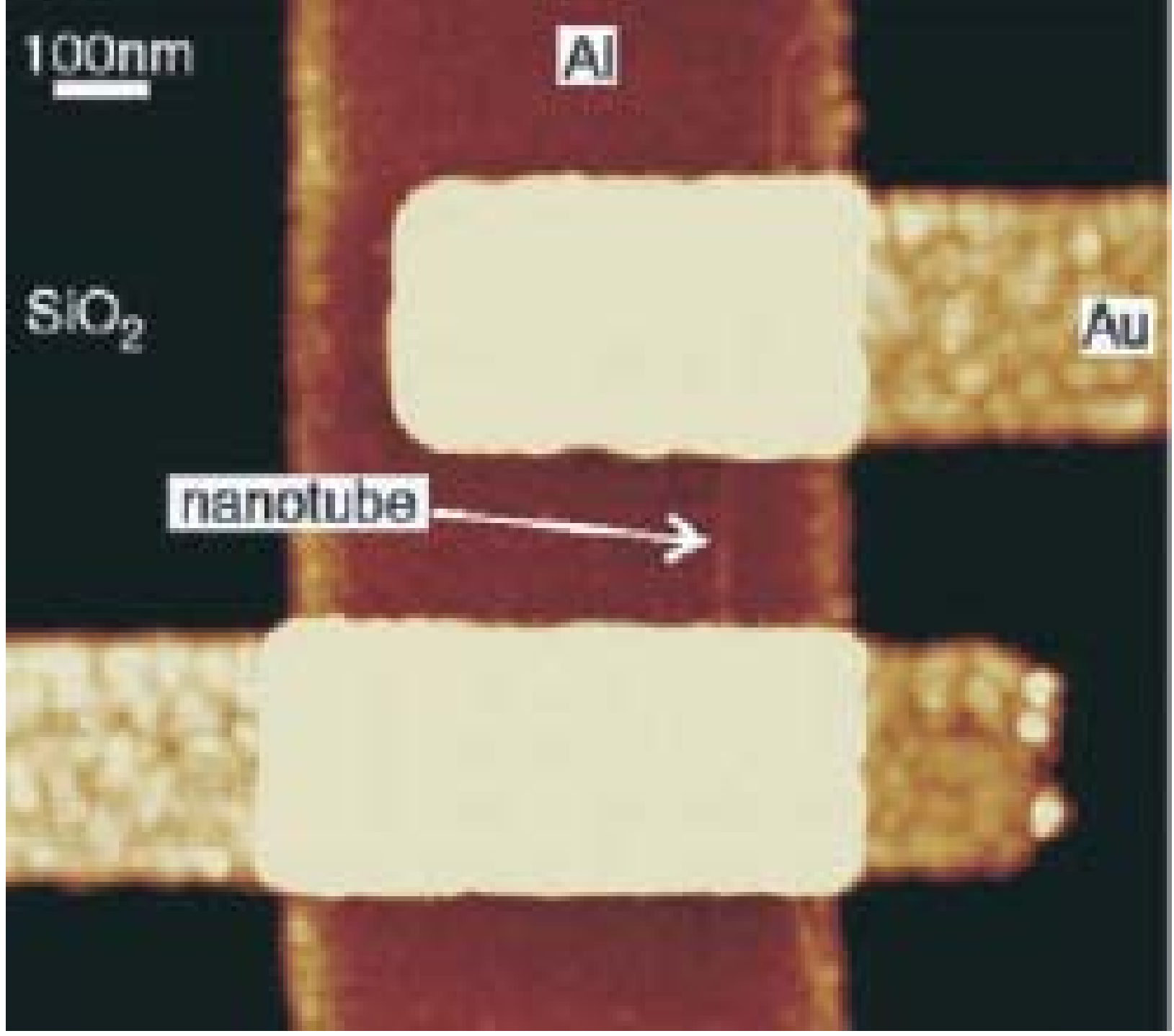
100nm

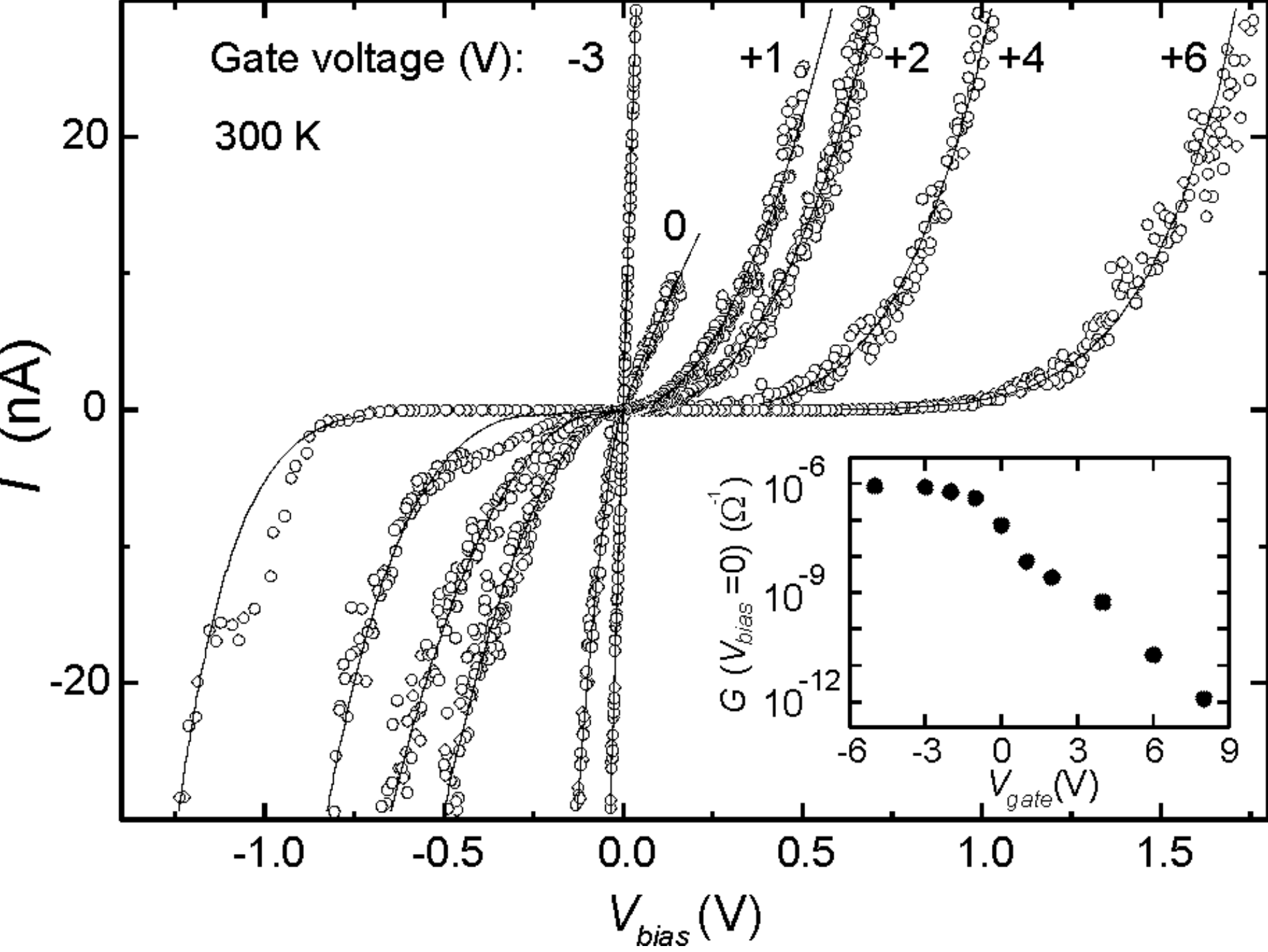
Al

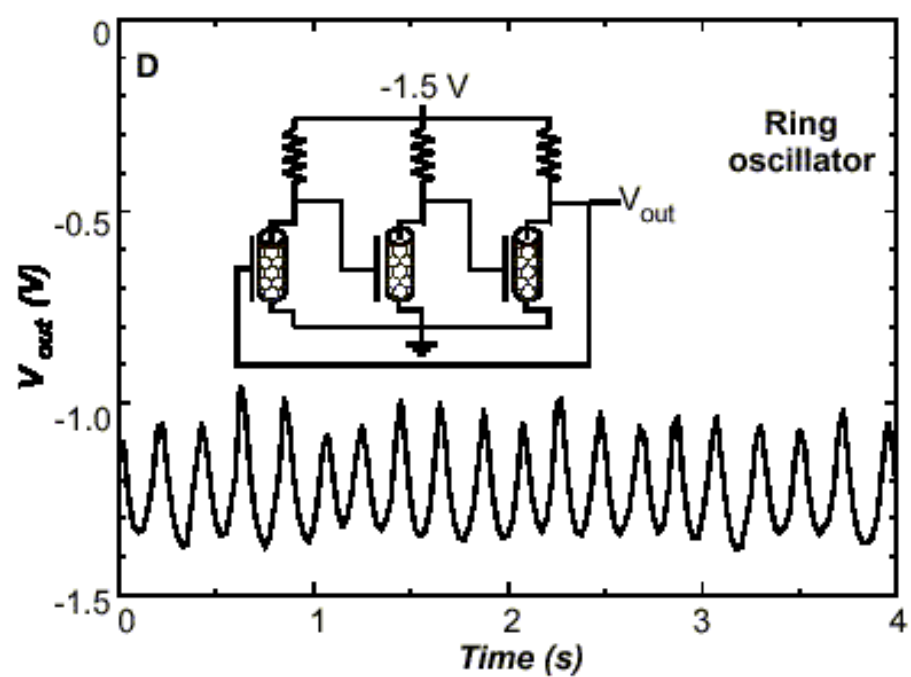
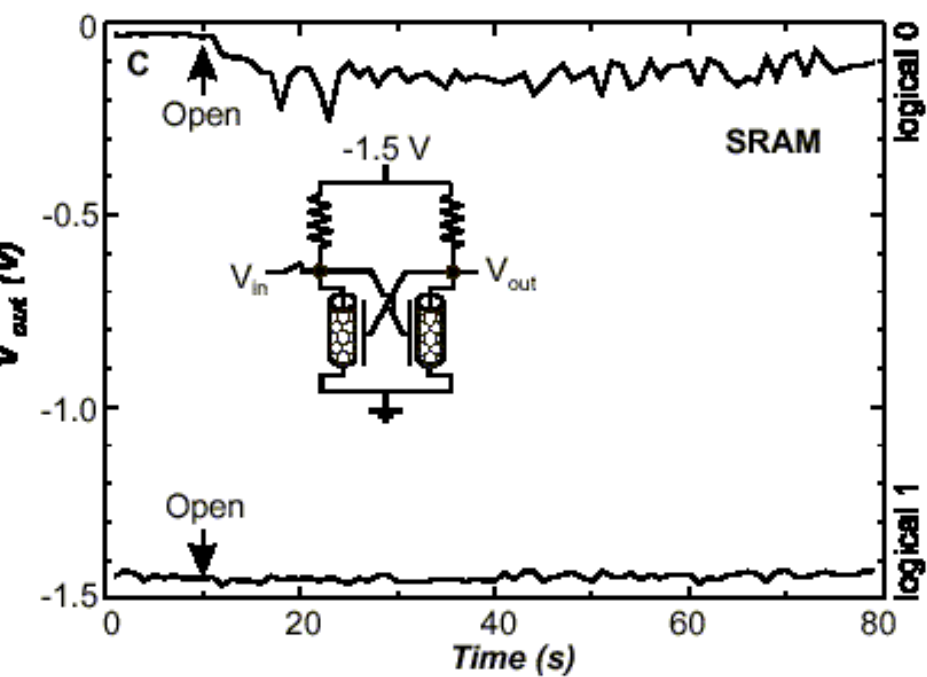
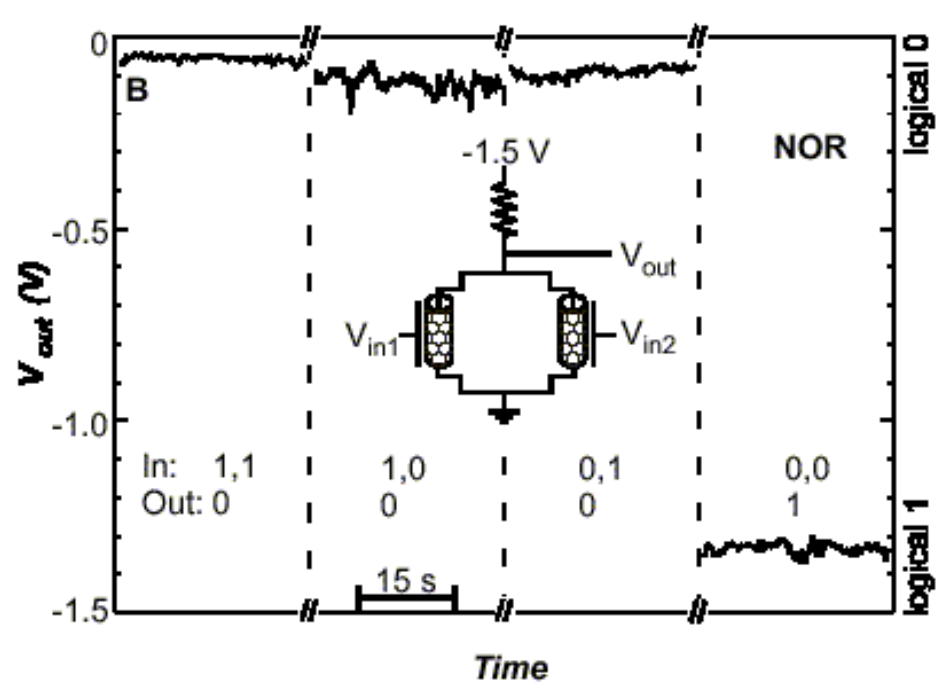
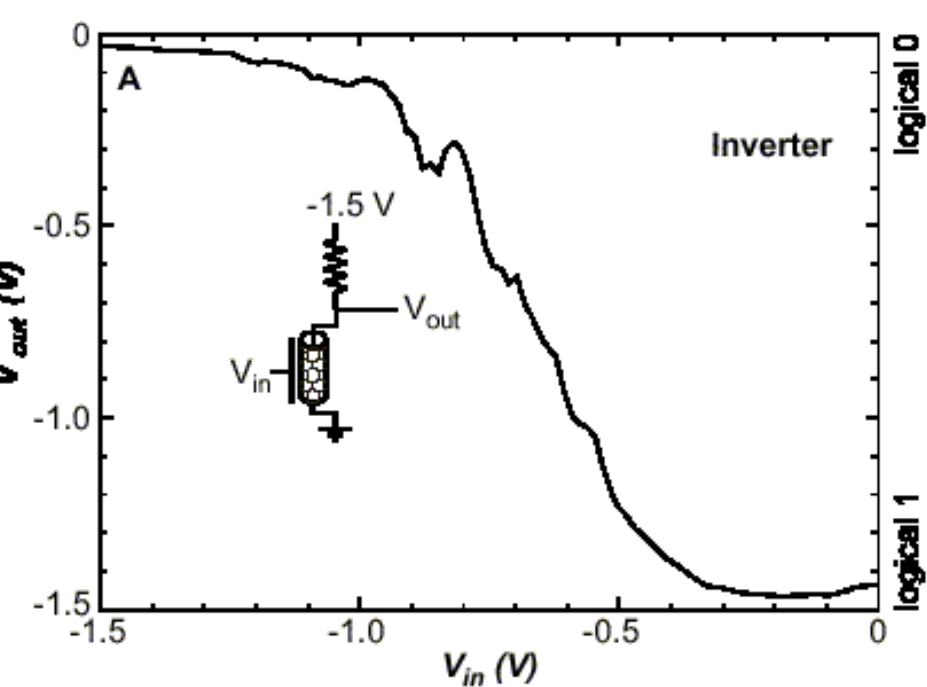
SiO<sub>2</sub>

Au

nanotube



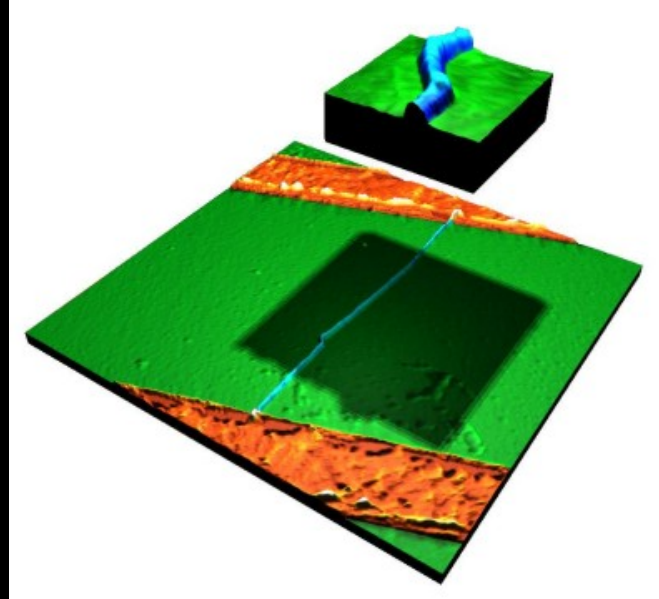
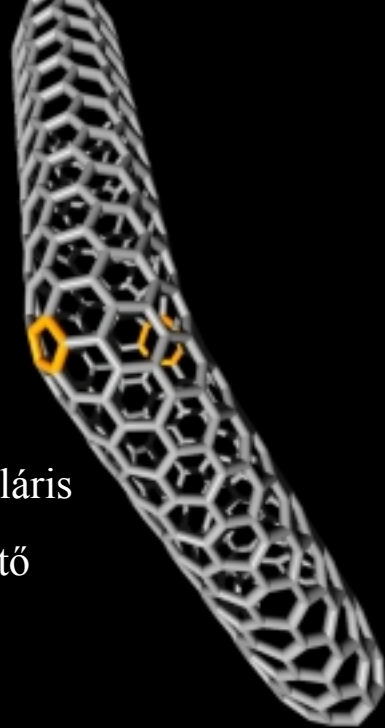




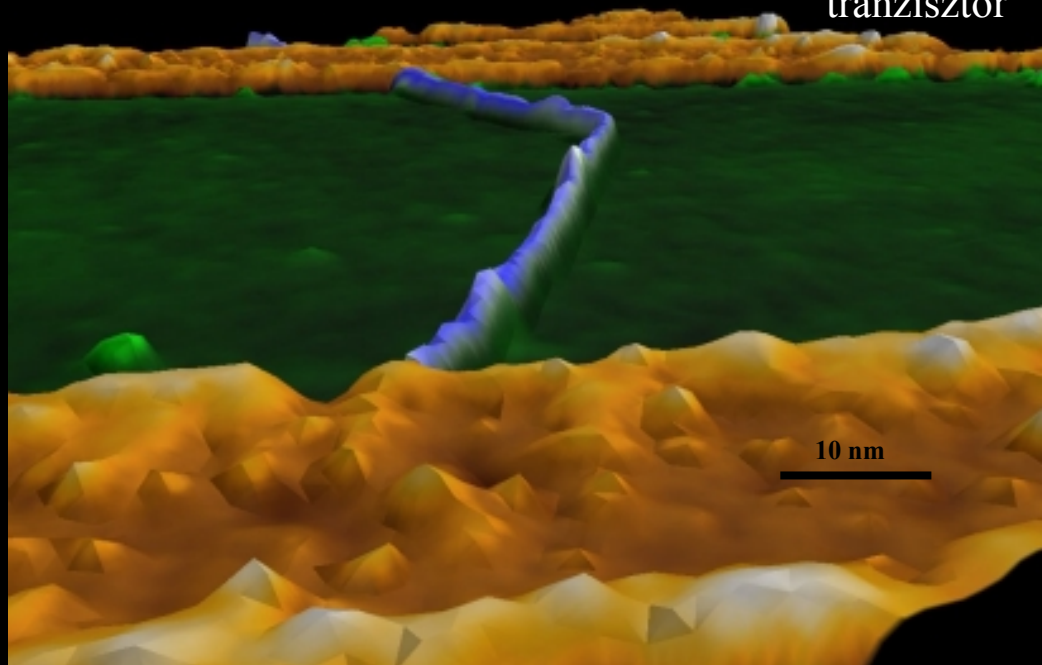




intramolekuláris  
fém-félvezető  
átmenet



szingli  
elektron  
tranzisztor

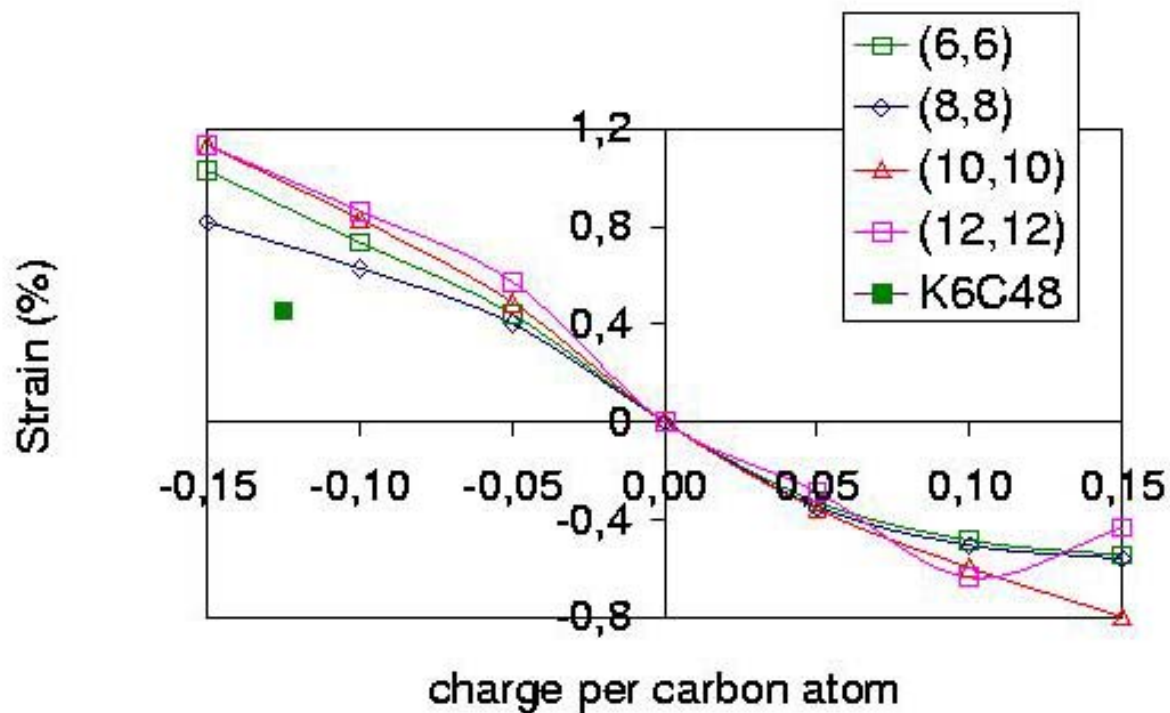


10 nm

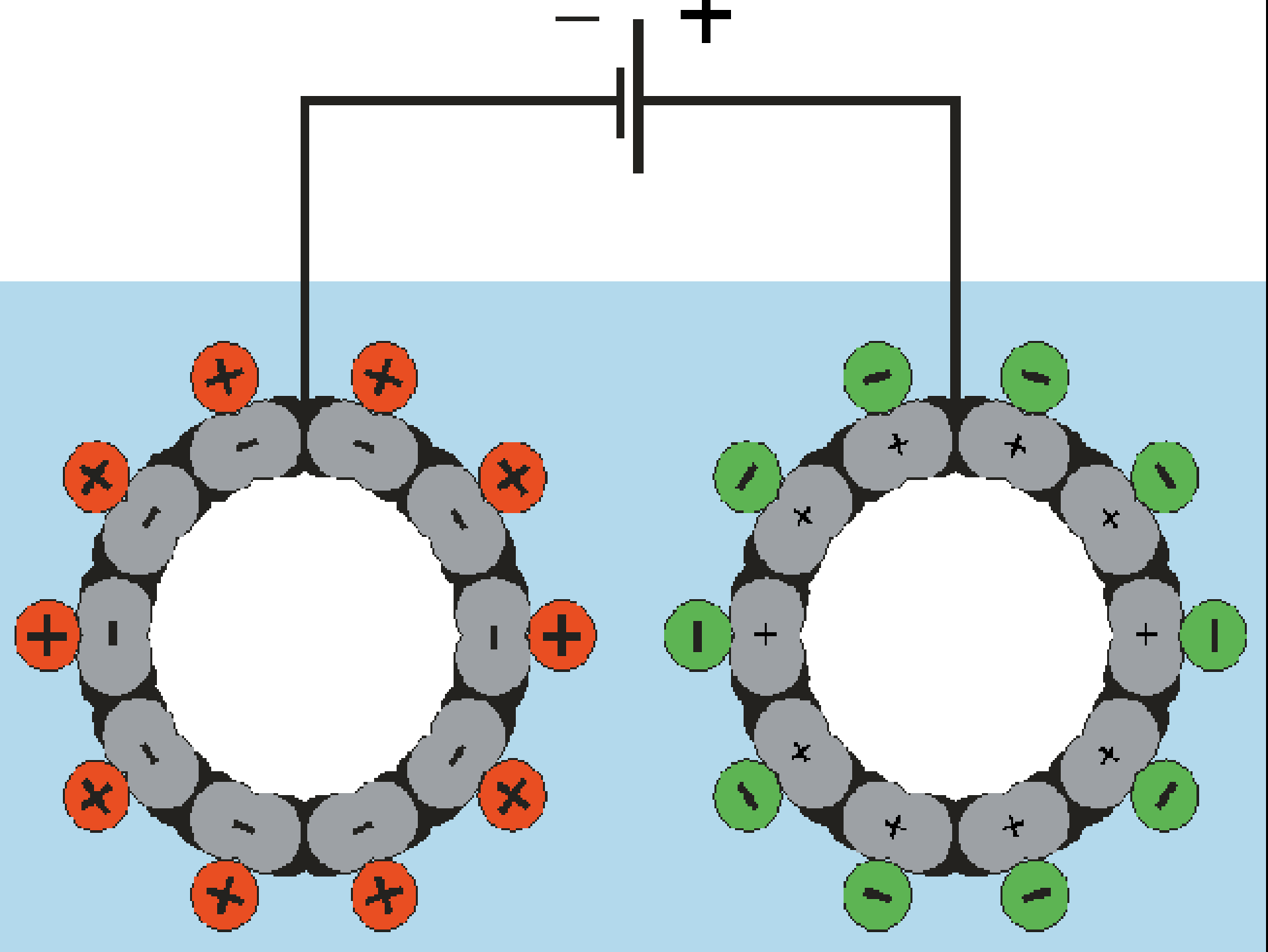
relatív megnyúlás

## Calculated strain vs charge in single-wall carbon nanotubes (n,n)

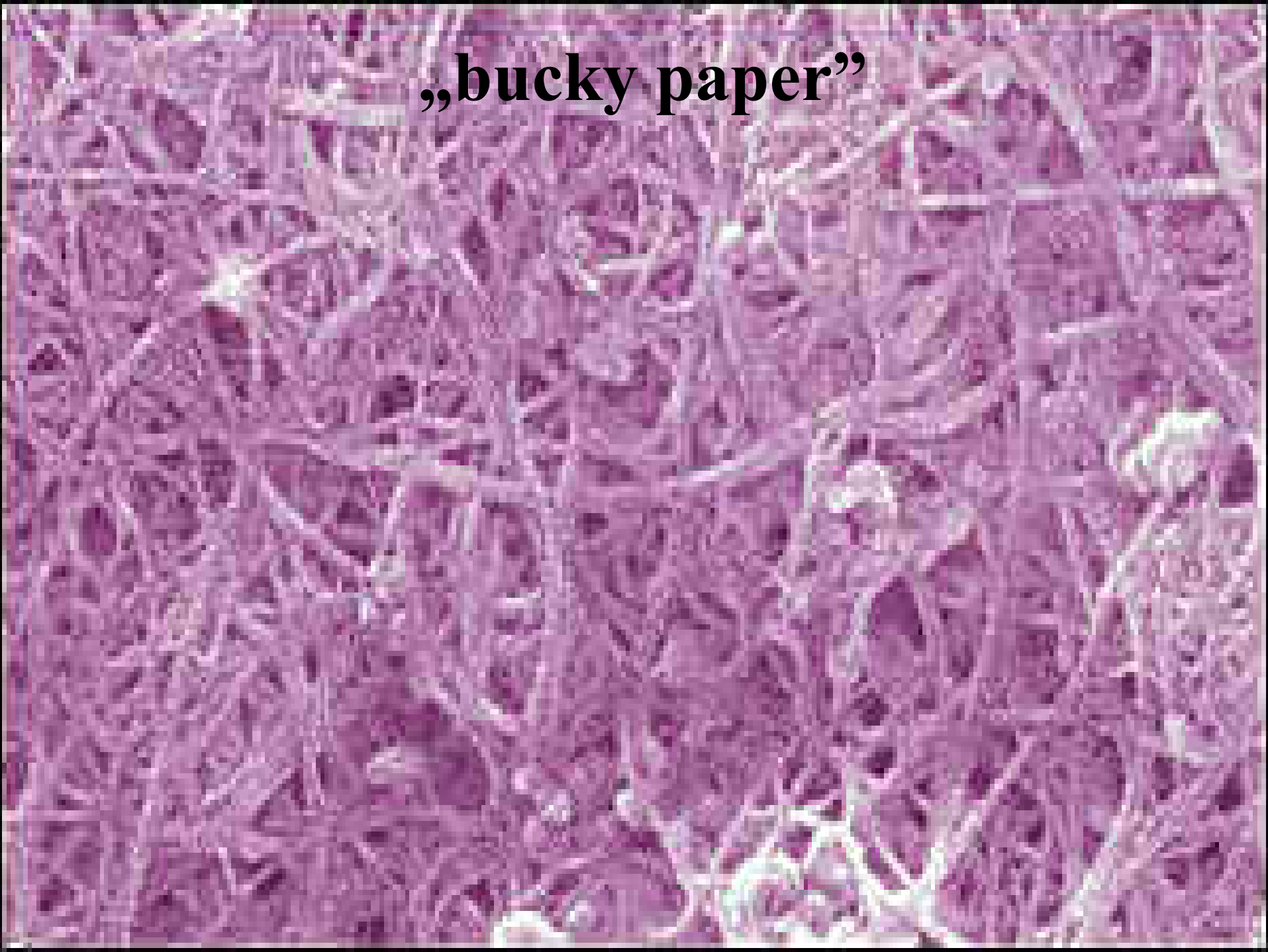
[VASP, GGA calculation, G. Sun, M. Kertesz, J. Kurti, R. Baughman]



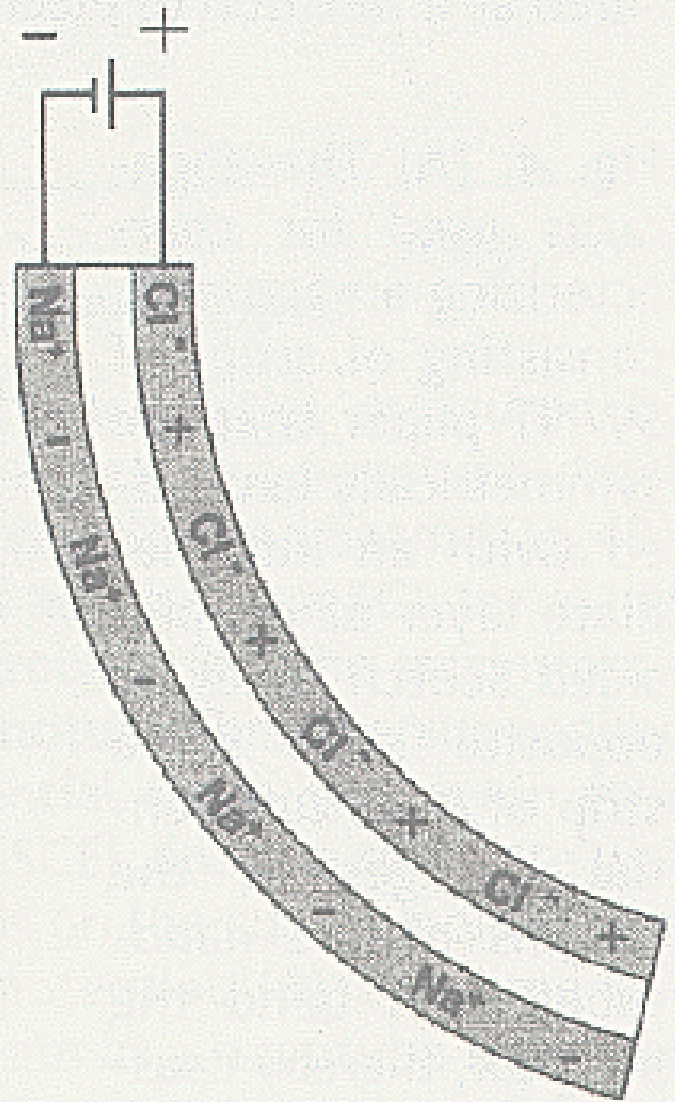
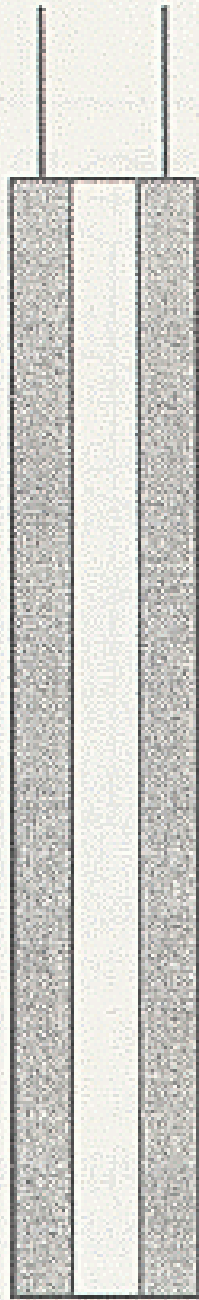
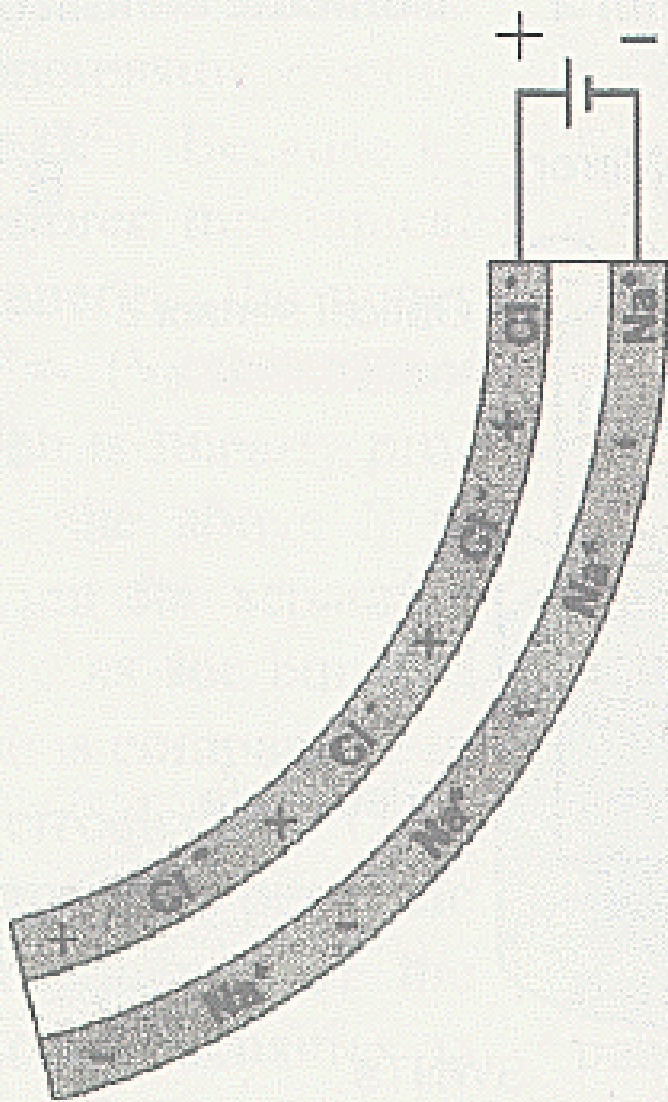
töltés / szénatom

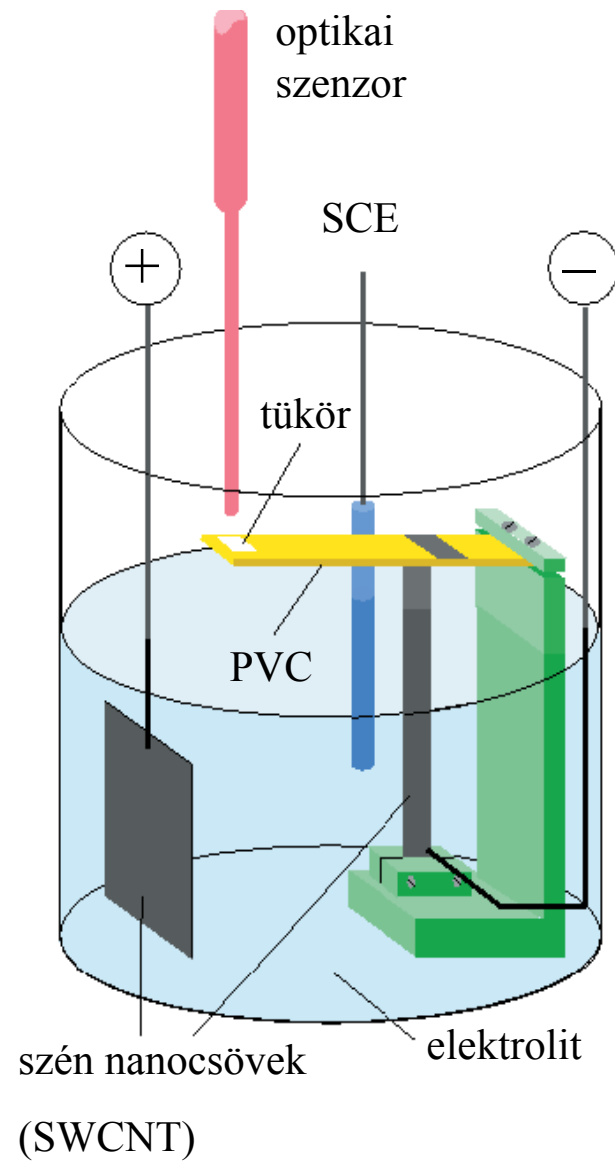
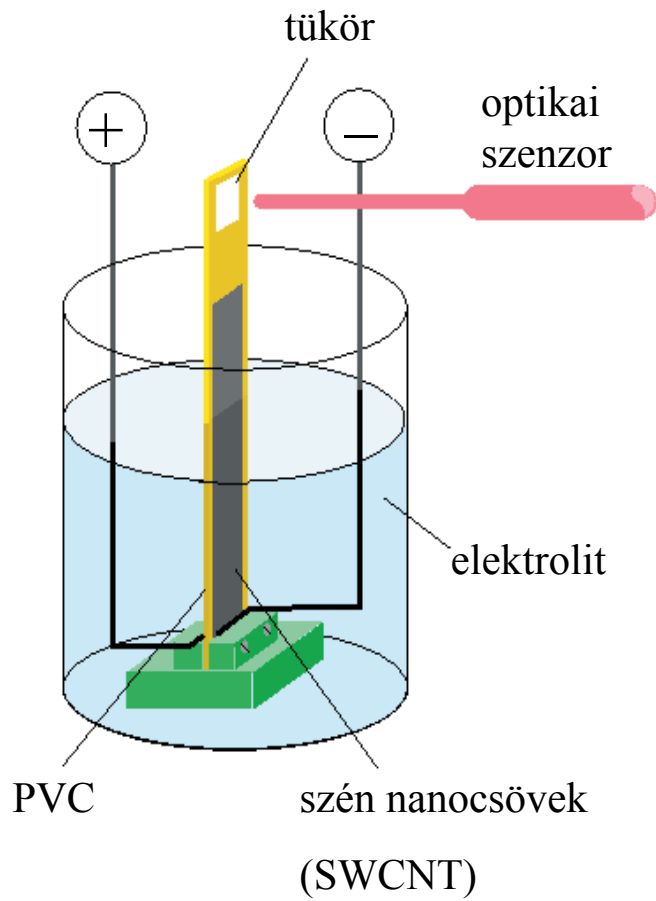


**„bucky paper”**



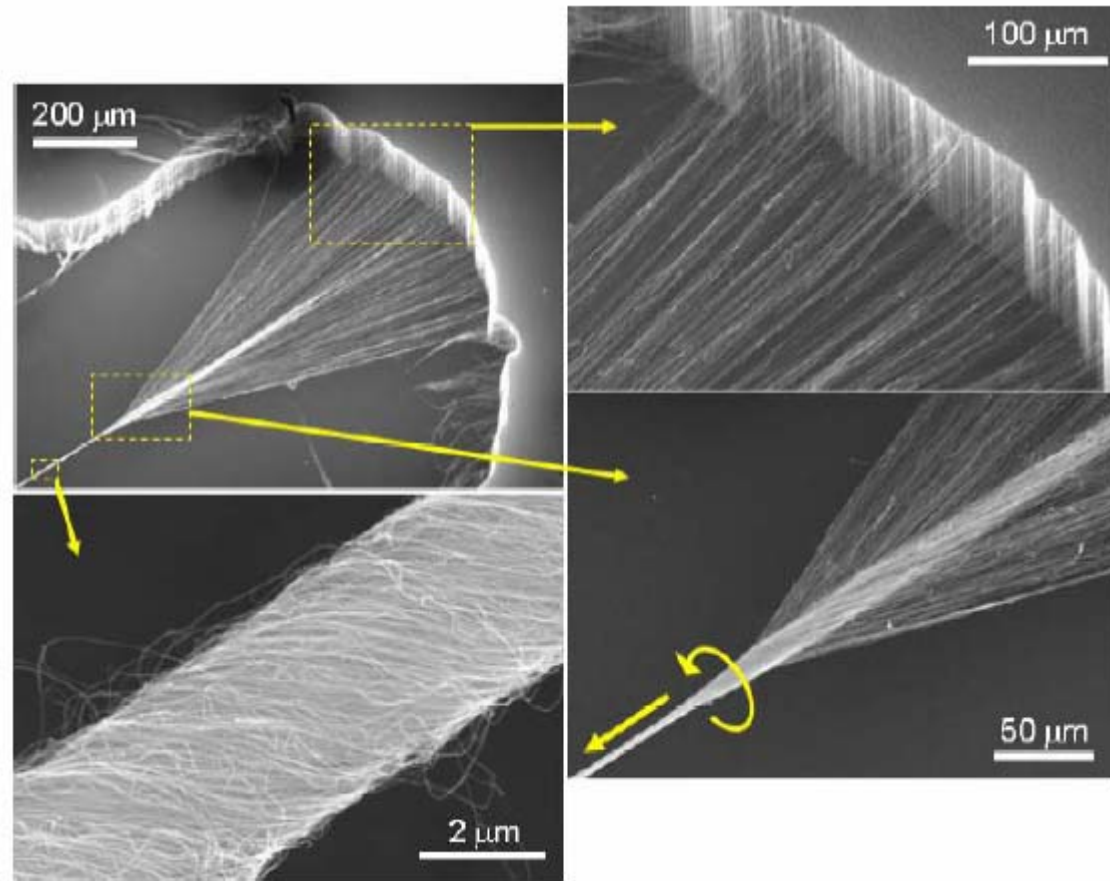
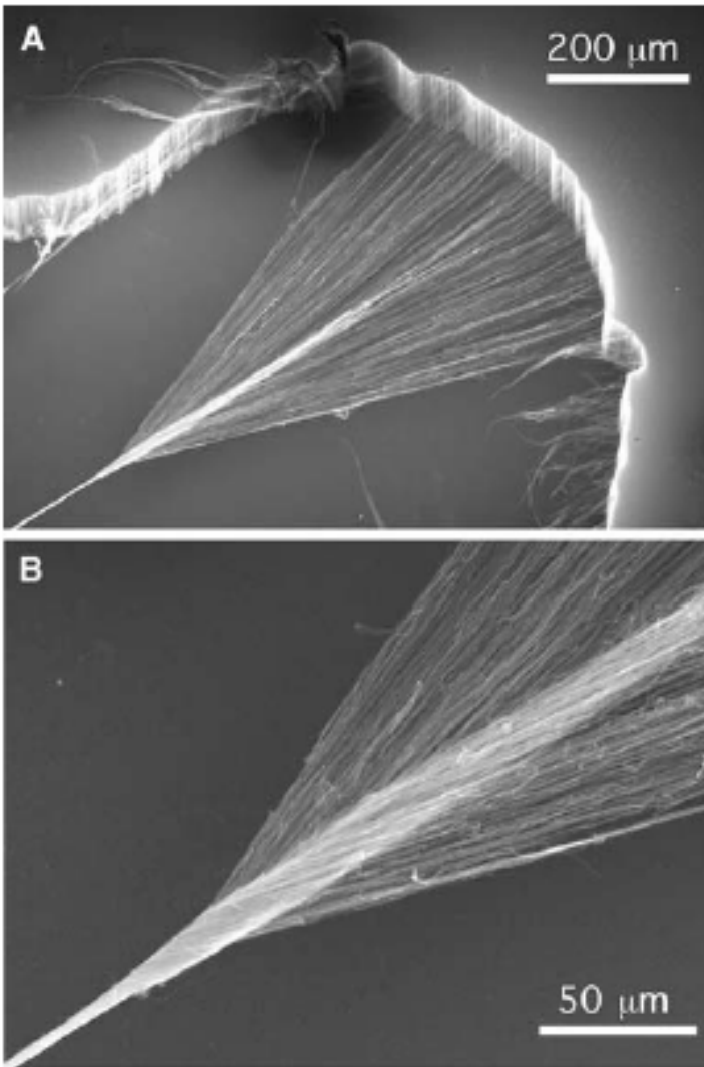






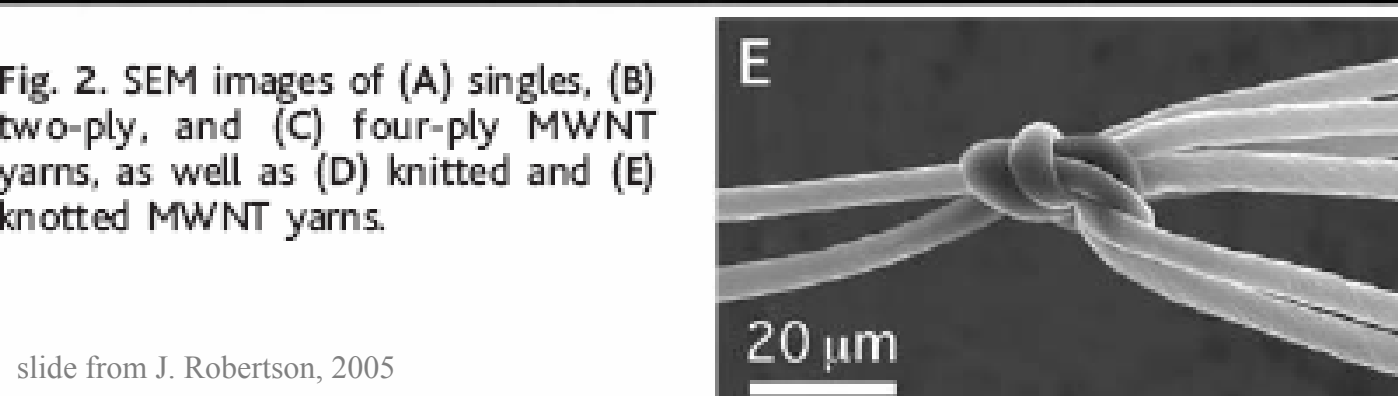
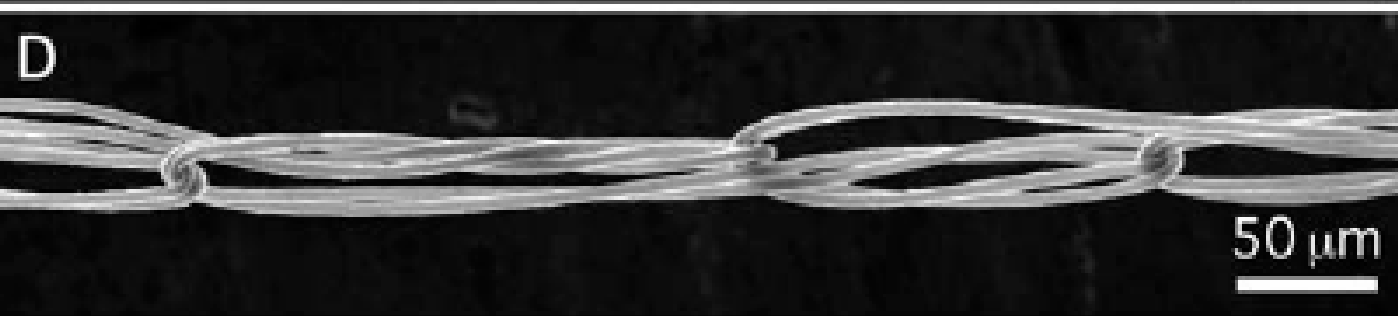
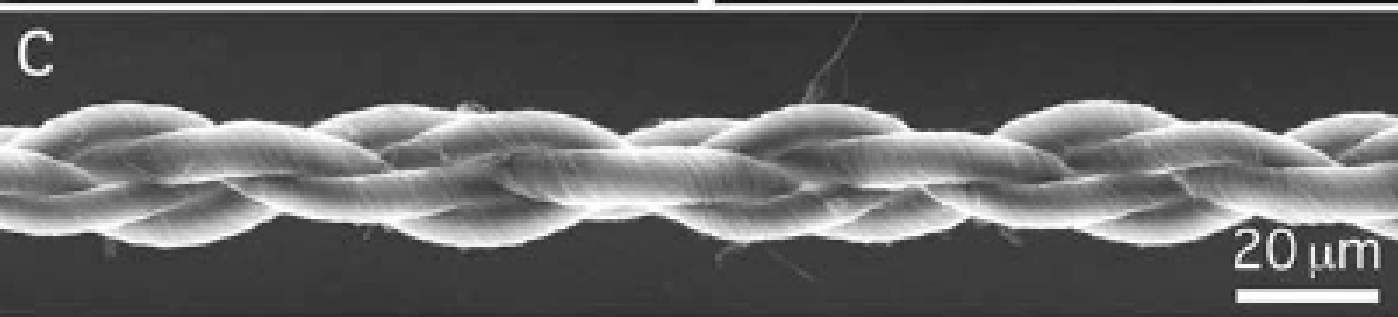
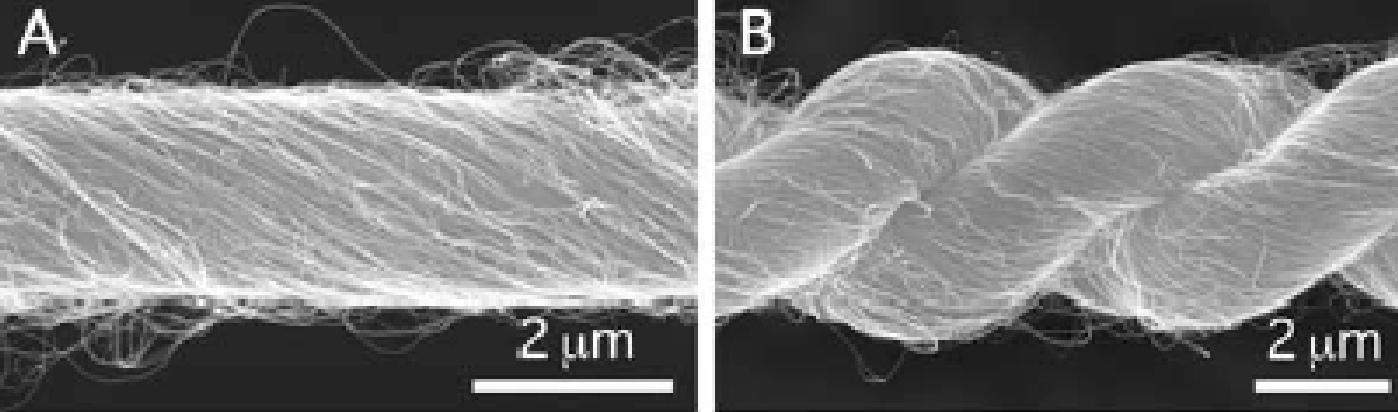
„mesterséges izom”

# Szén nanocső szőnyegből szőtt fonal



Zhang, Baughman, Science 306 1356 (2004)

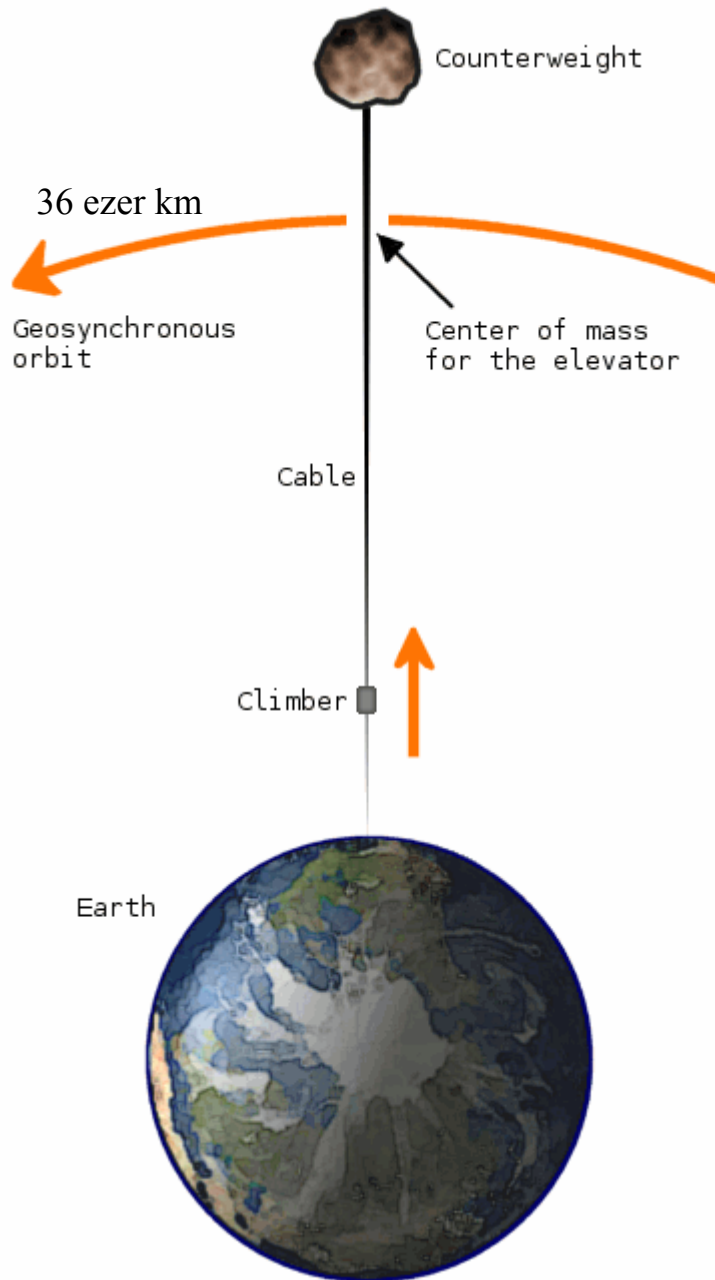




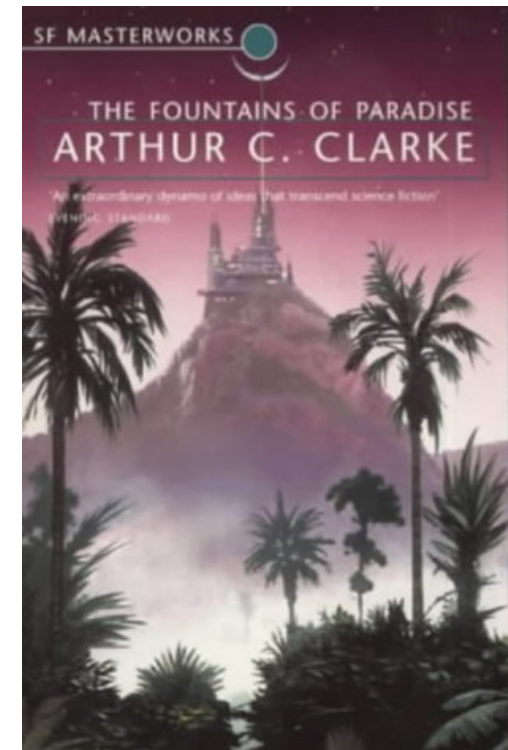
## Szén nanocső fonalak csomózása

Fig. 2. SEM images of (A) singles, (B) two-ply, and (C) four-ply MWNT yarns, as well as (D) knitted and (E) knotted MWNT yarns.

# „ÜRLIFT“



The Fountains of Paradise  
by Arthur C. Clarke  
Sci-Fi (1979)



## Szén nanocsövek összehasonlítása más anyagokkal

Anyag	Young modulus (GPa)	Szakító-szilárdság (GPa)	Sűrűség (g/cm <sup>3</sup> )
SWNT	1054	30	1.3
MWNT	1200	30	2.6
Szénszál	250-700	2-3	1.8-2.1
Acél	208	0.4	7.8
„Epoxid”	3.5	0.005	1.25
Fa	16	0.008	0.6

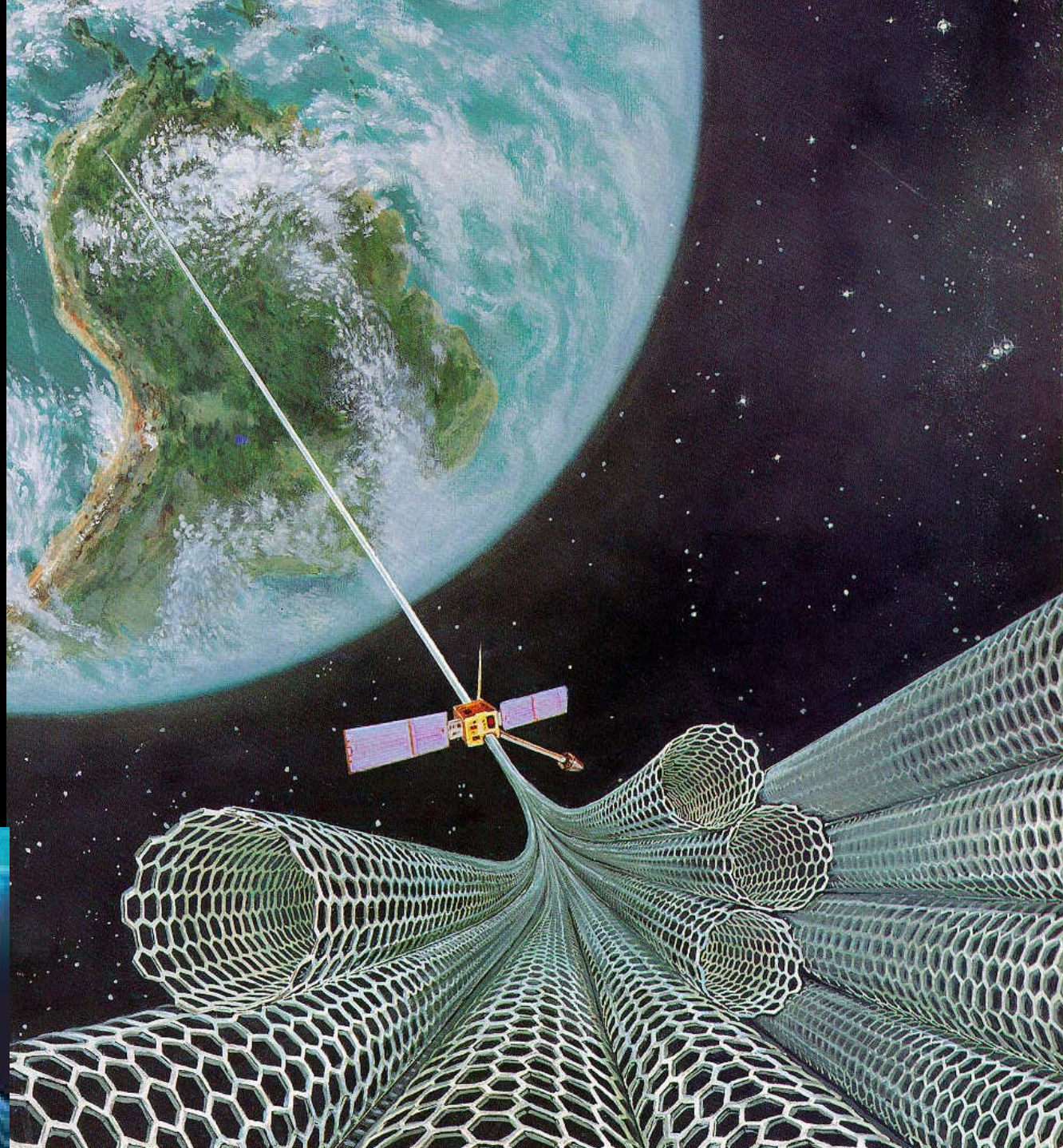
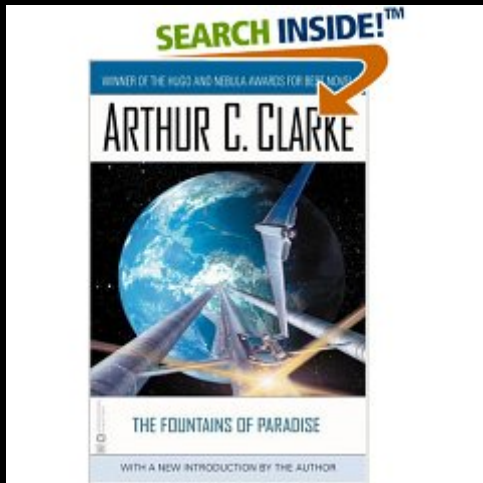


„ÚRLIFT“

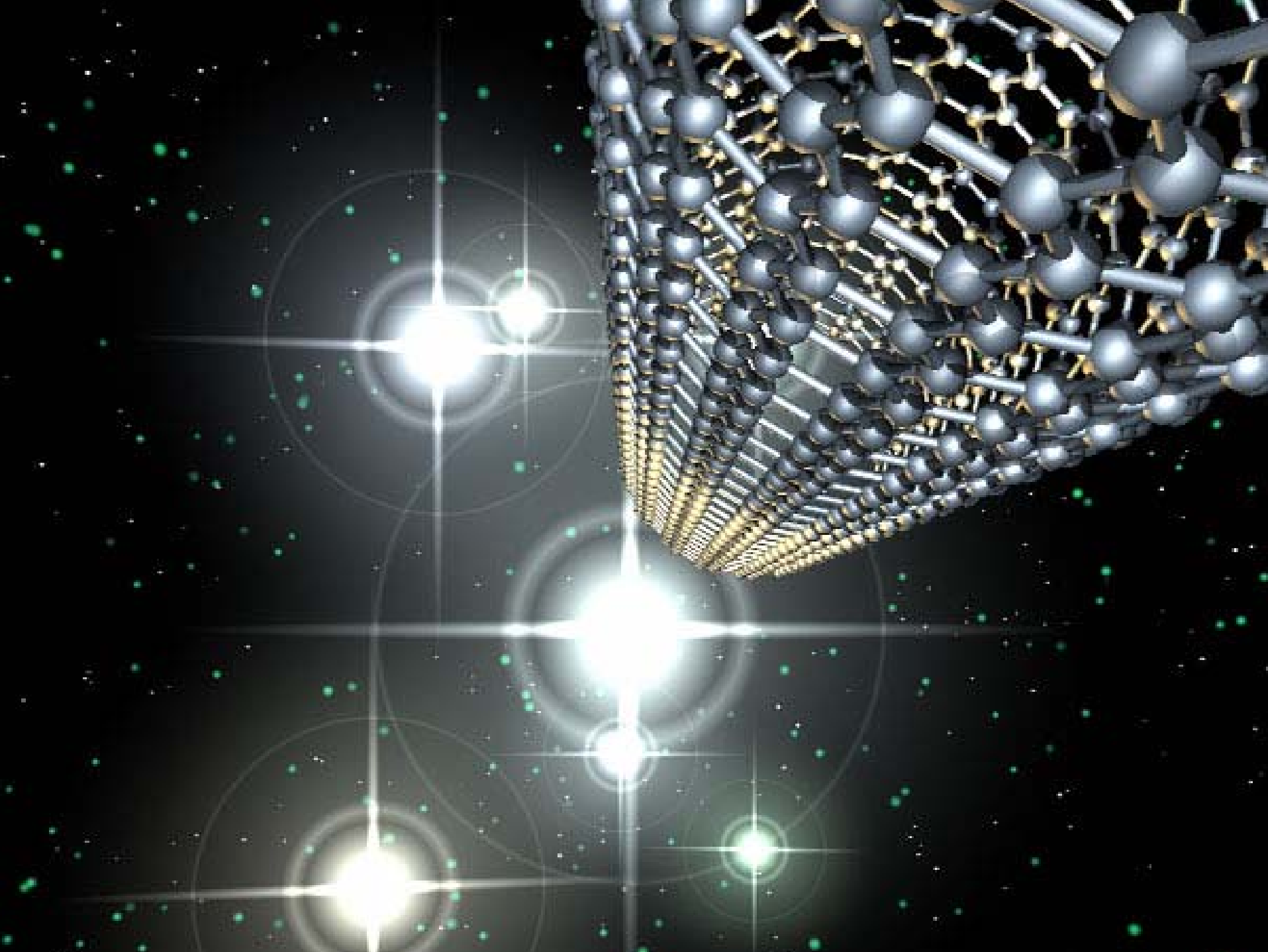
The Fountains of Paradise

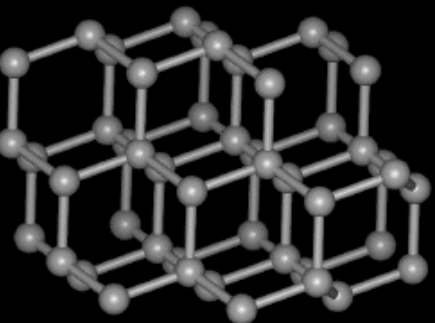
by Arthur C. Clarke

Sci-Fi (1979)

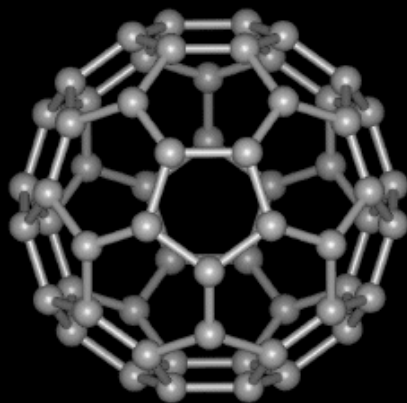




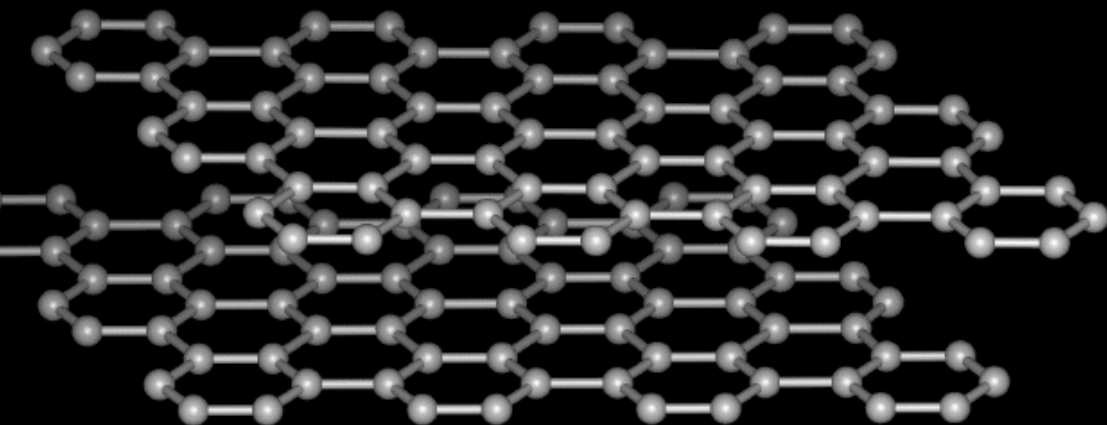




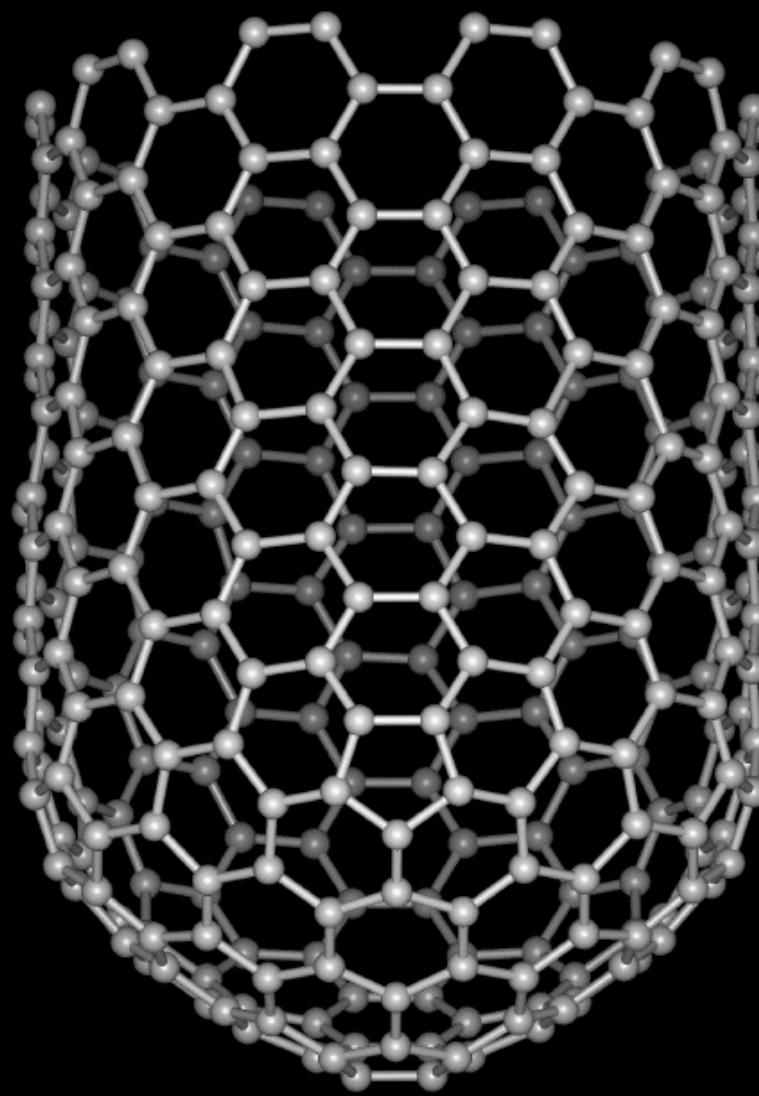
gyémánt



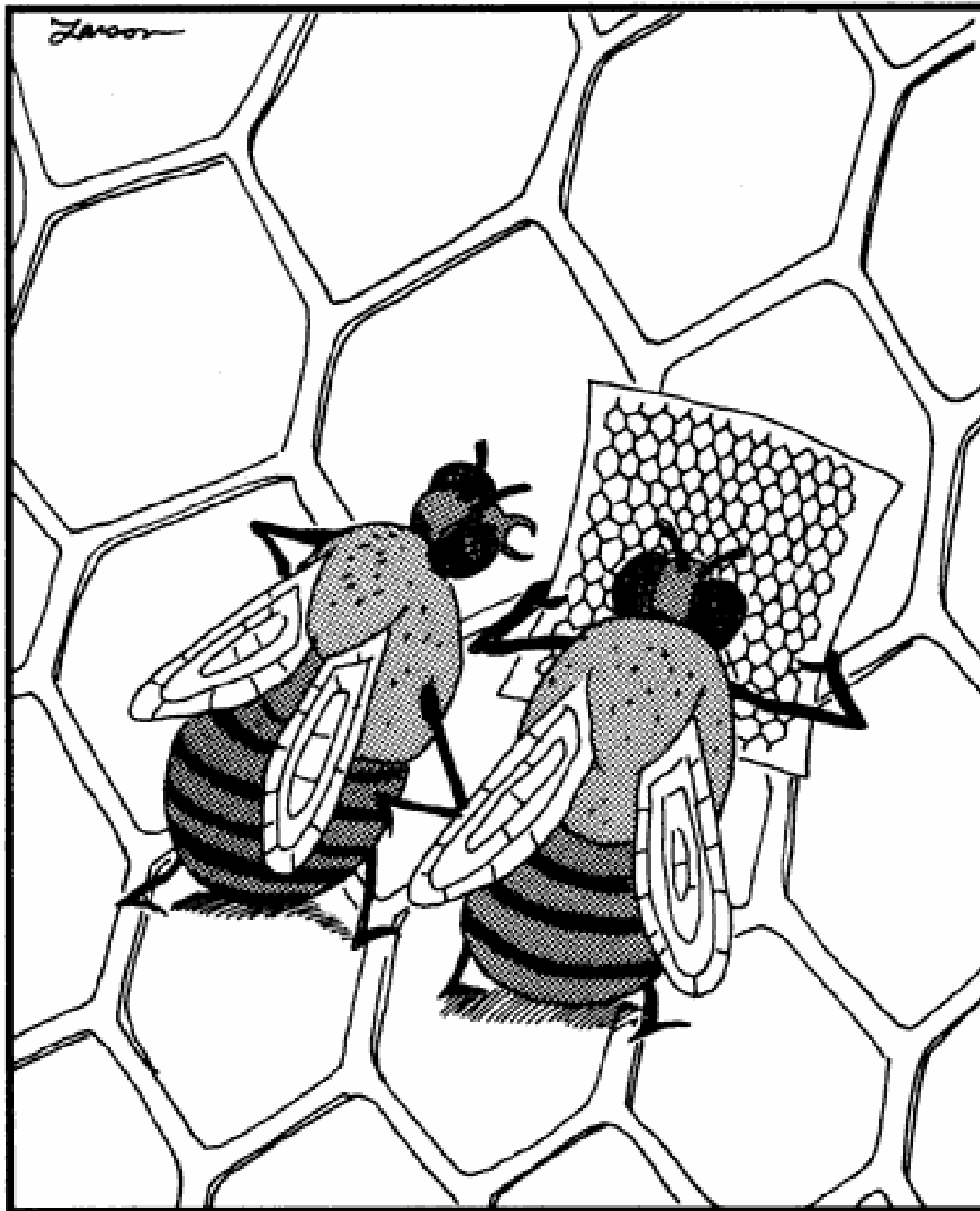
fullerén(ek)



grafit



nanocsö(vek)



**"Face it, Fred—you're lost!"**