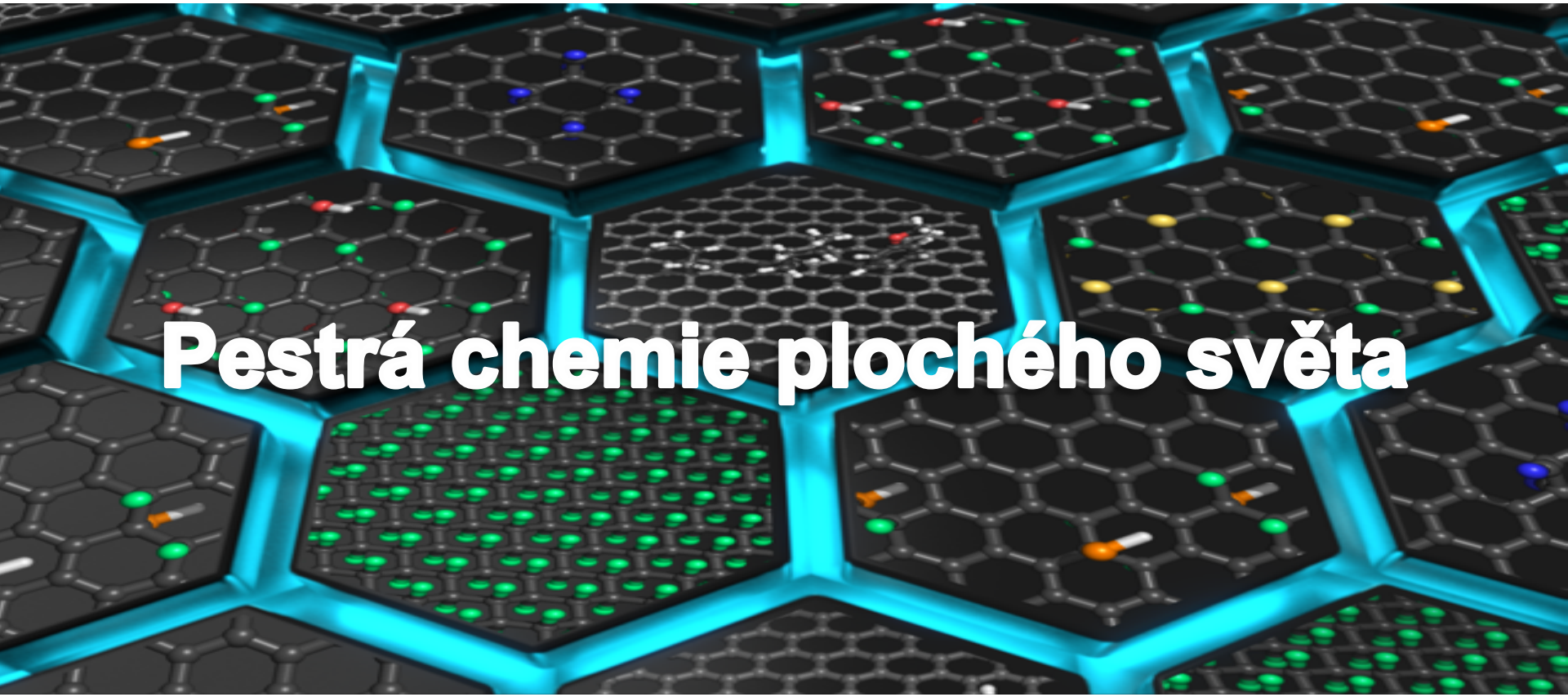
REGIONÁLNÍ CENTRUM POKROČILÝCH TECHNOLOGIÍ A MATERIÁLŮ
Regional Centre of Advanced Technologies and Materials

Univerzita Palackého v Olomouci



Pestrá chemie plochého světa

Michal Otyepka

Regionální centrum pokročilých technologií a materiálů

katedra fyzikální chemie

Přírodovědecká fakulta, Univerzita Palackého v Olomouci

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10^{21} m

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10^7

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10^0 m

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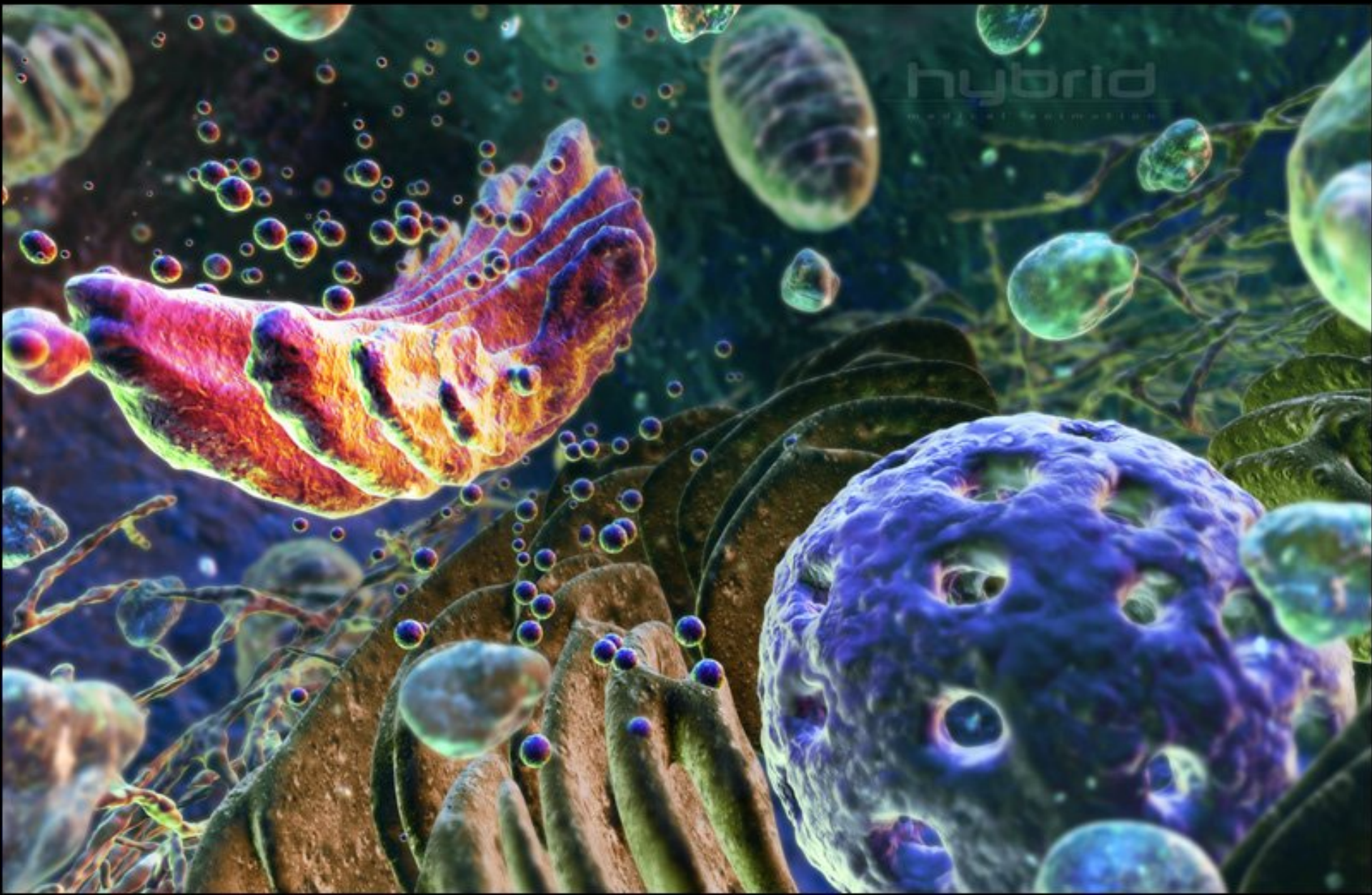
10^{-6} m



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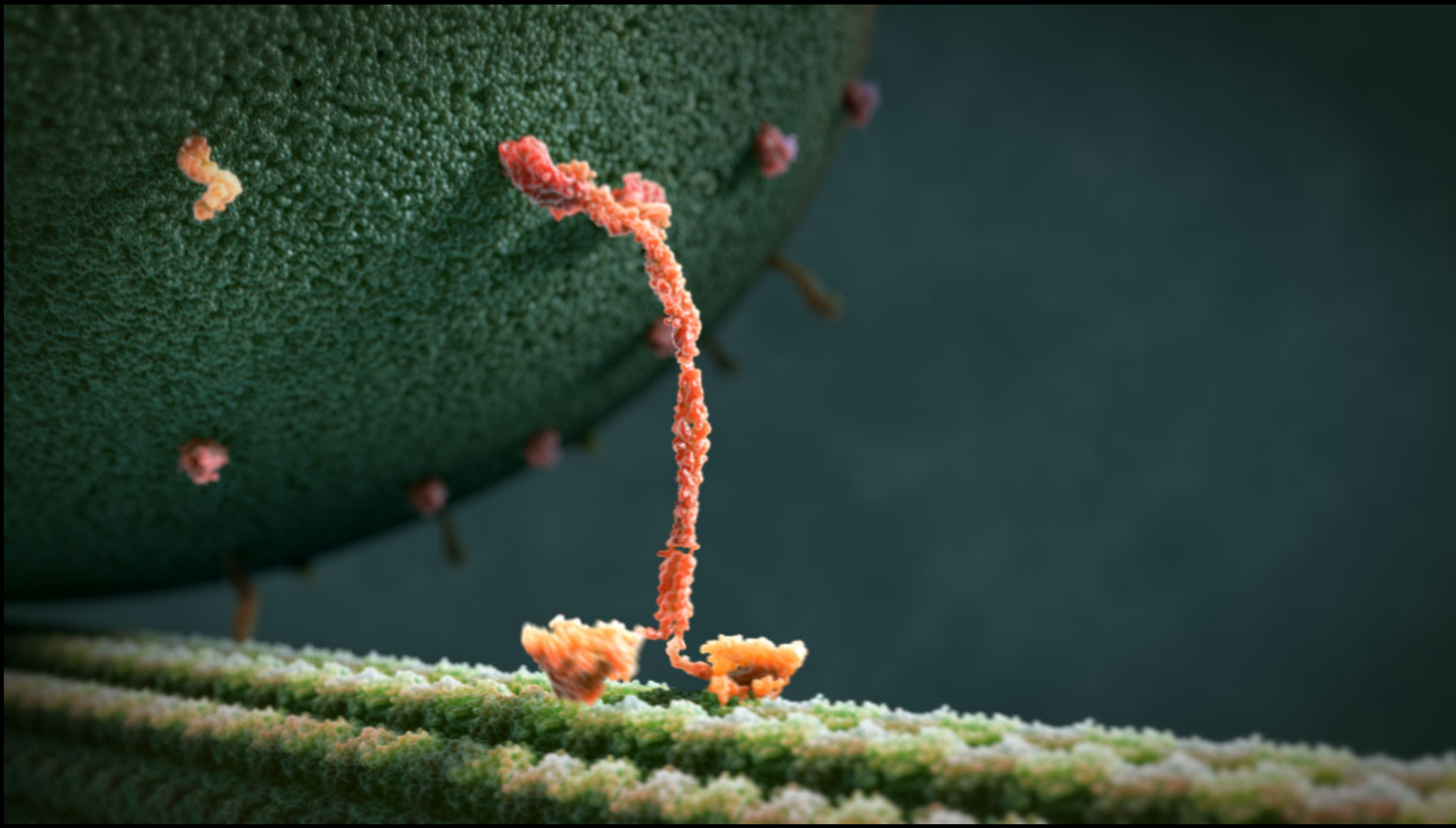
10^{-7} m



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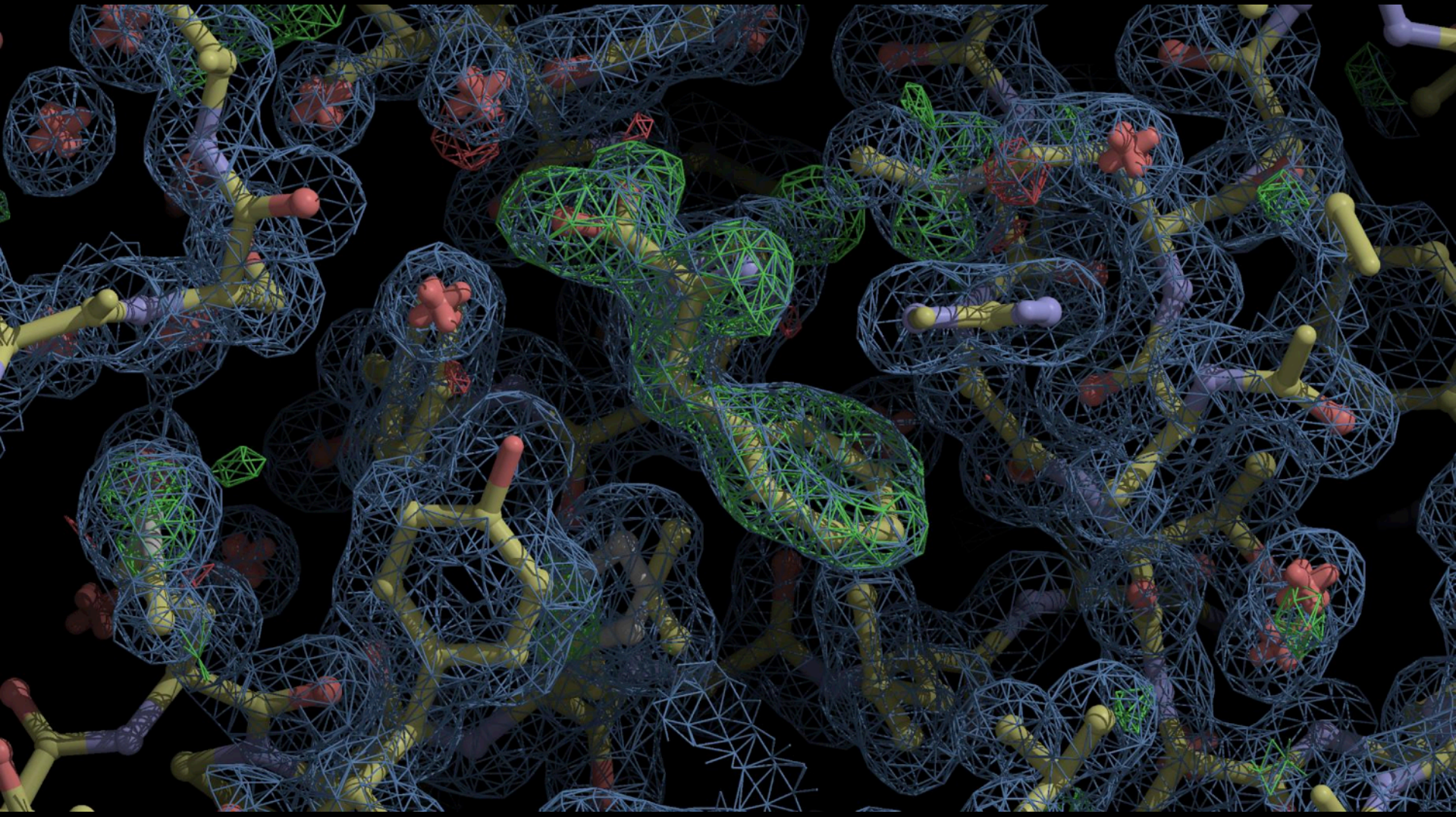
10^{-9} m



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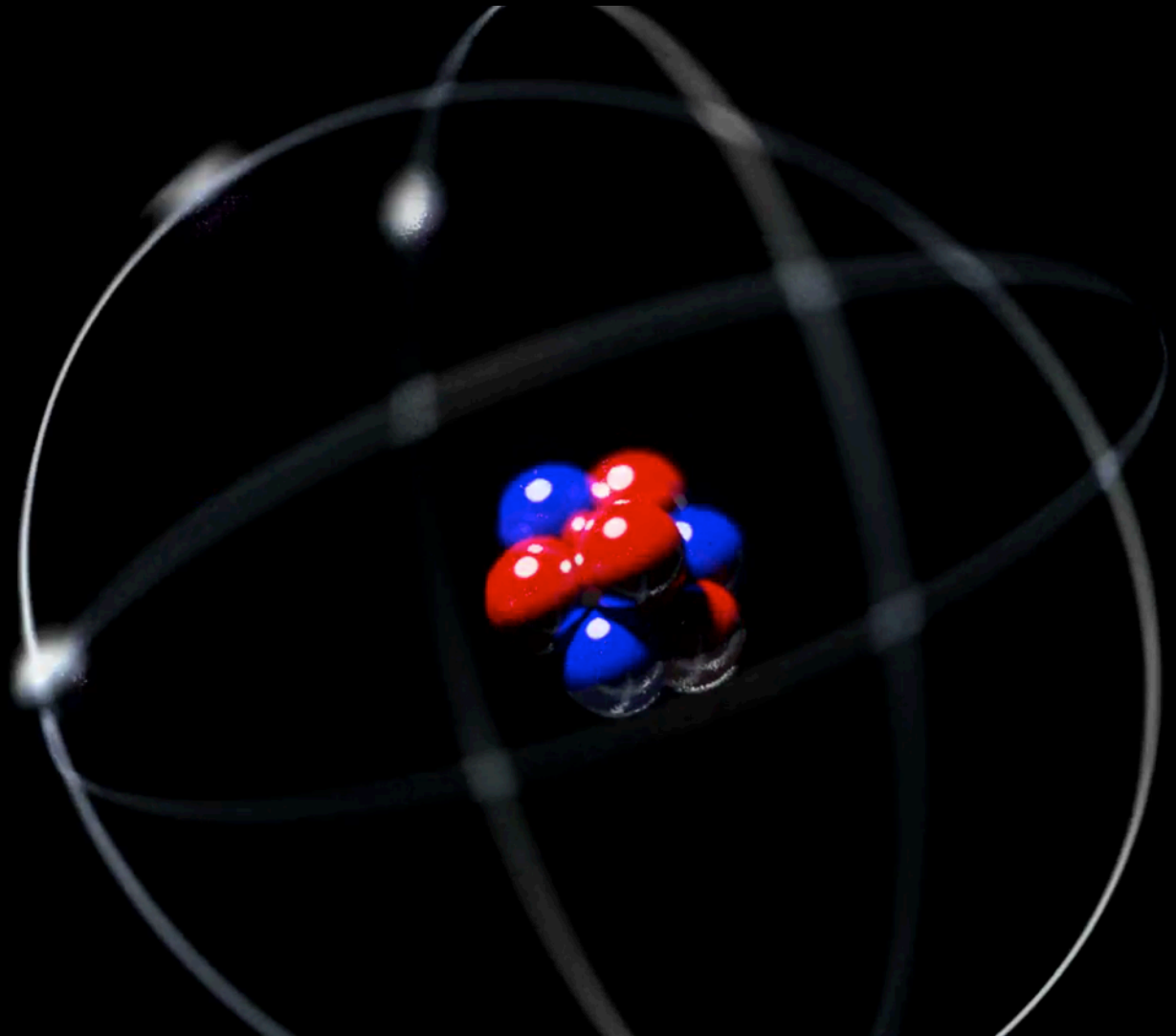
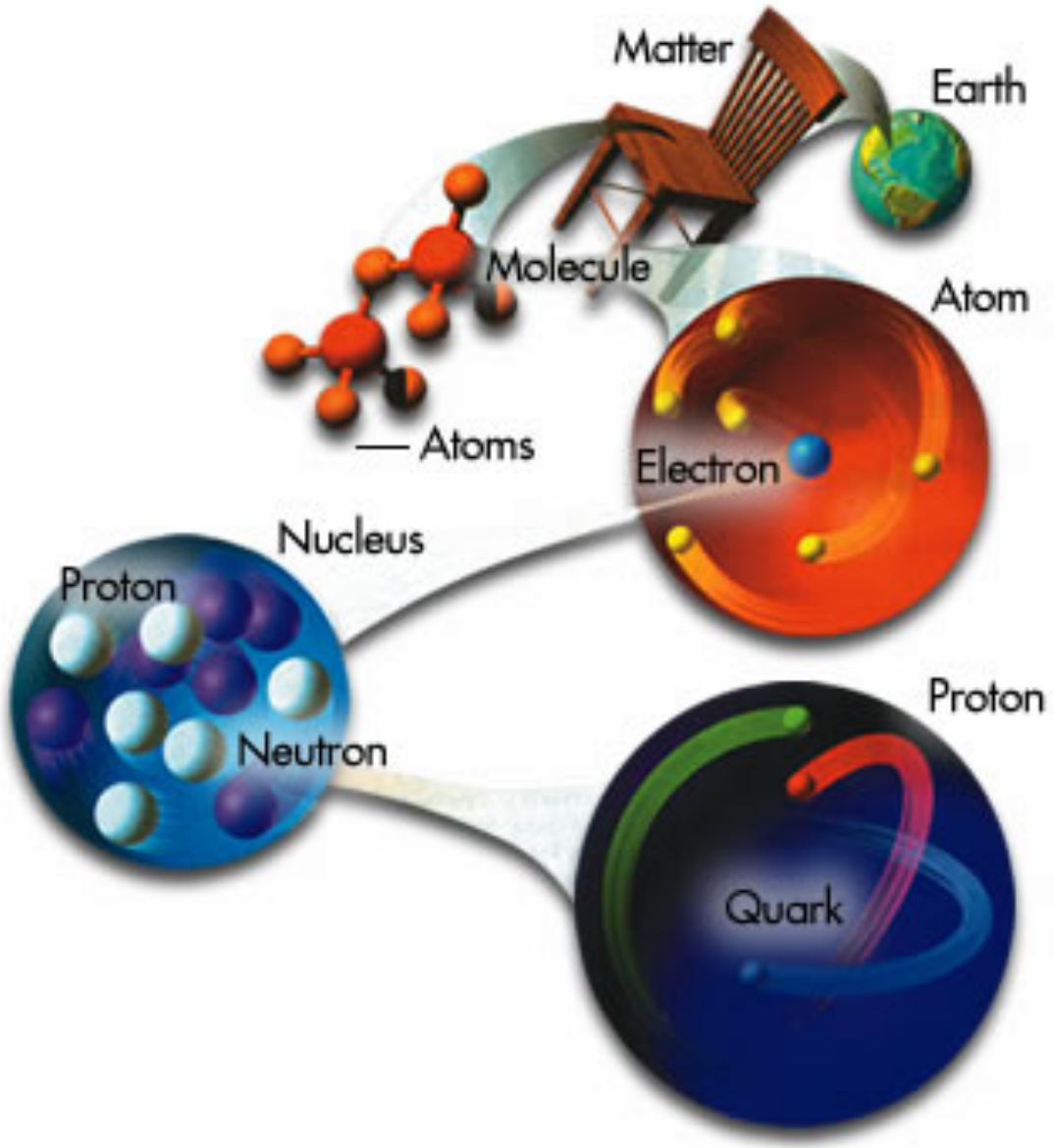
10^{-10} m



10^{-14} m

ty škály



10^{7}

10^{0}

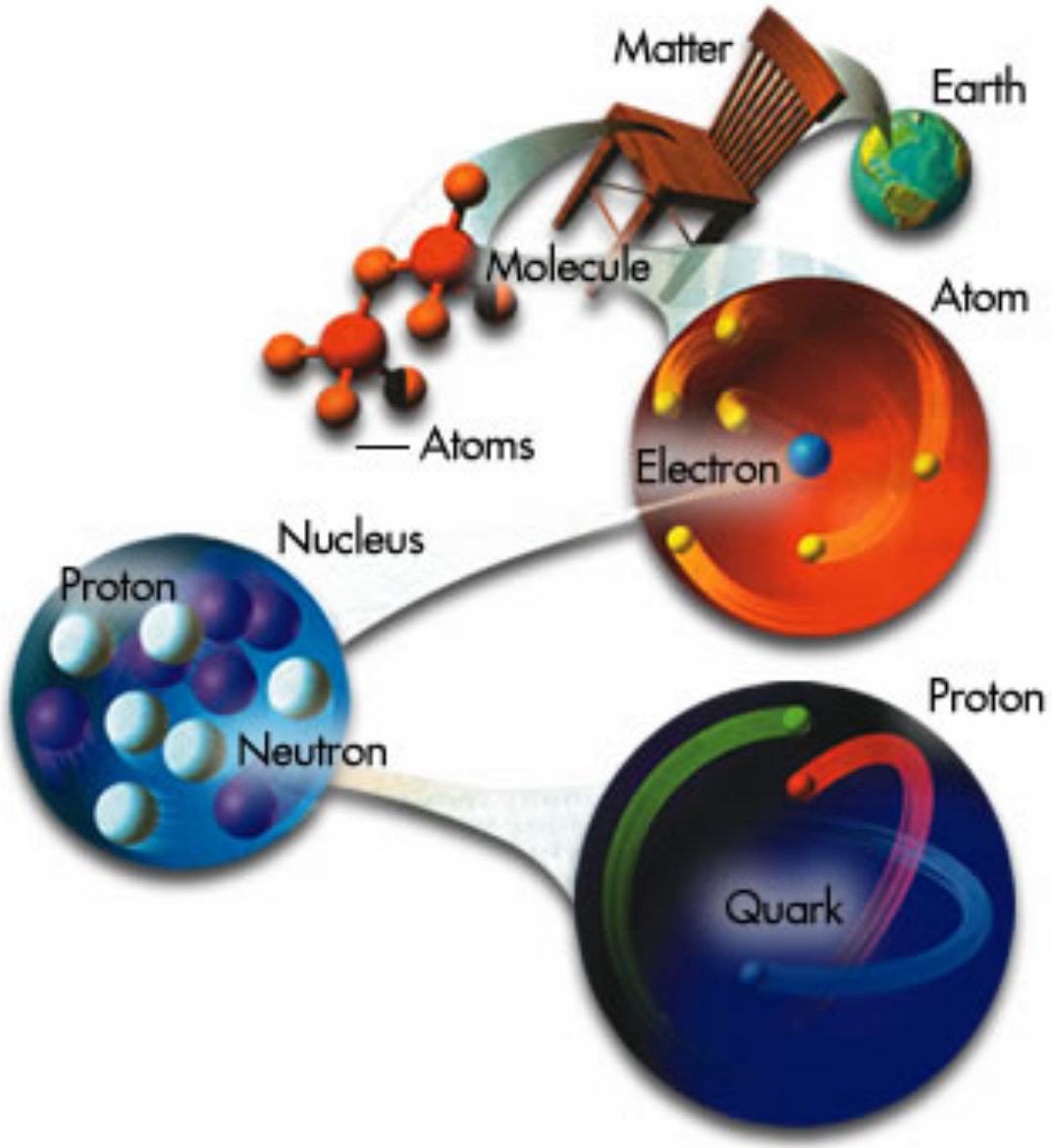
10^{-8}

10^{-10}

10^{-15}

m

nano



10^{7}

10^{0} 10^{-3} mili

10^{-6} mikro

10^{-8} 10^{-9} nano

10^{-12} piko

10^{-15} 10^{-15} femto

m

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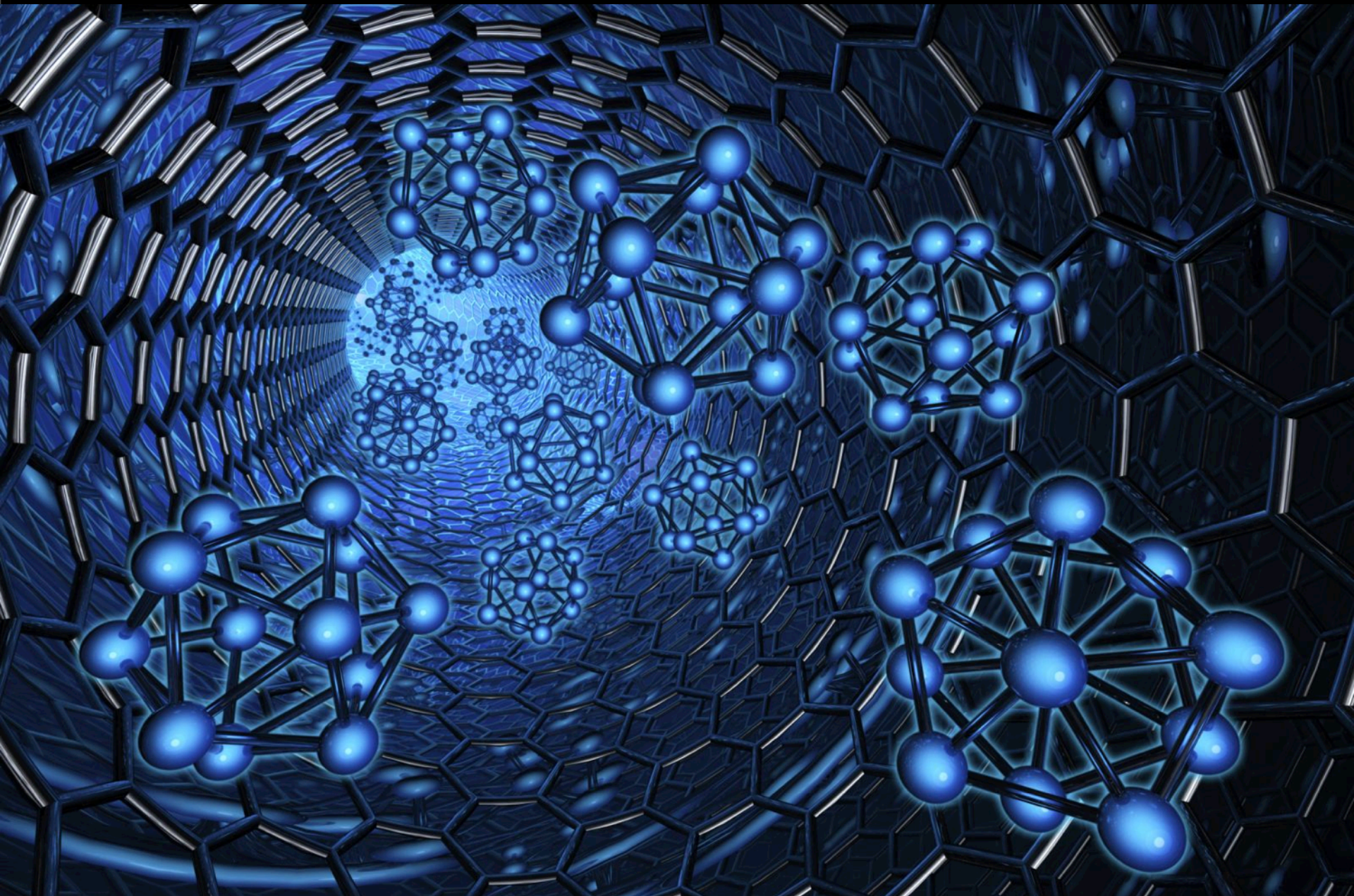
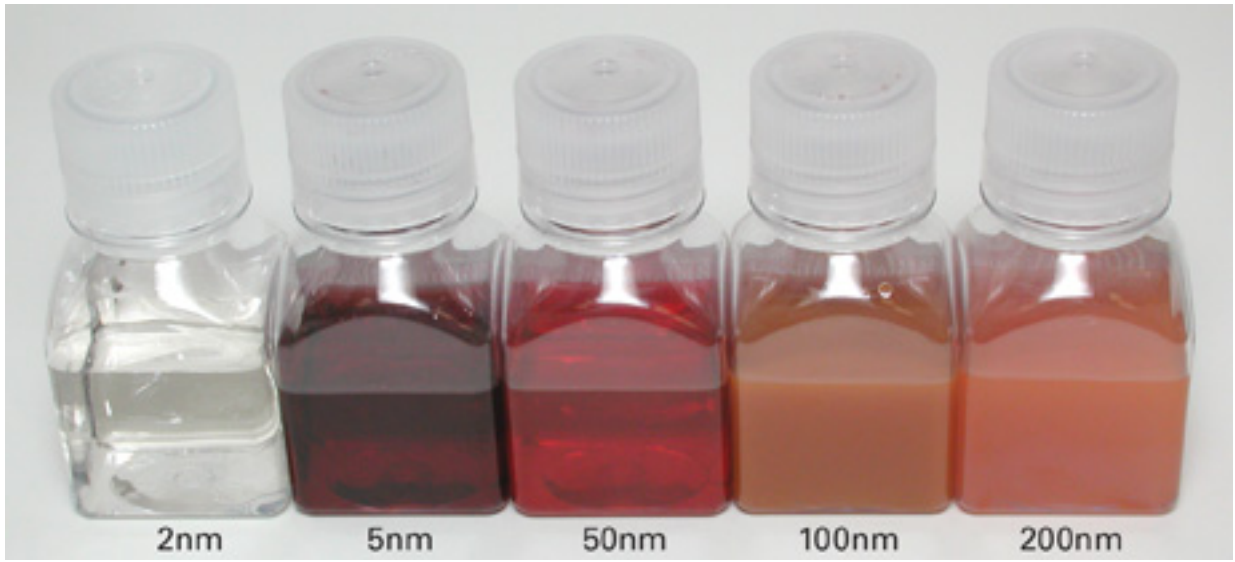
Proč NANO?



Proč je nano v kurzu?

Vlastnosti závisí na velikosti. Na velikosti záleží!

Tatáž látka s jinou velikostí částic



Koloid jakého kovu vidíte?

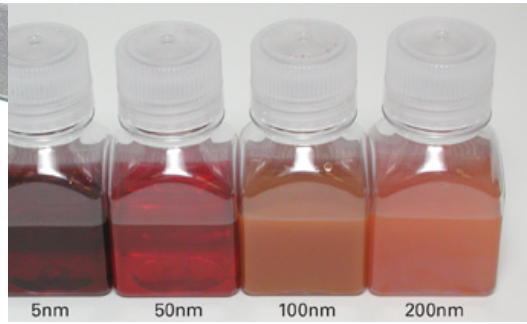
Koloid Au

Au s jinou velikostí částic

Nanotechnologie známe dlouho!

Lykurgův pohár, 4té století n.l. – Alexandrie?

Obsahuje koloidní (nanoskopické) částice Au a Ag ve skle



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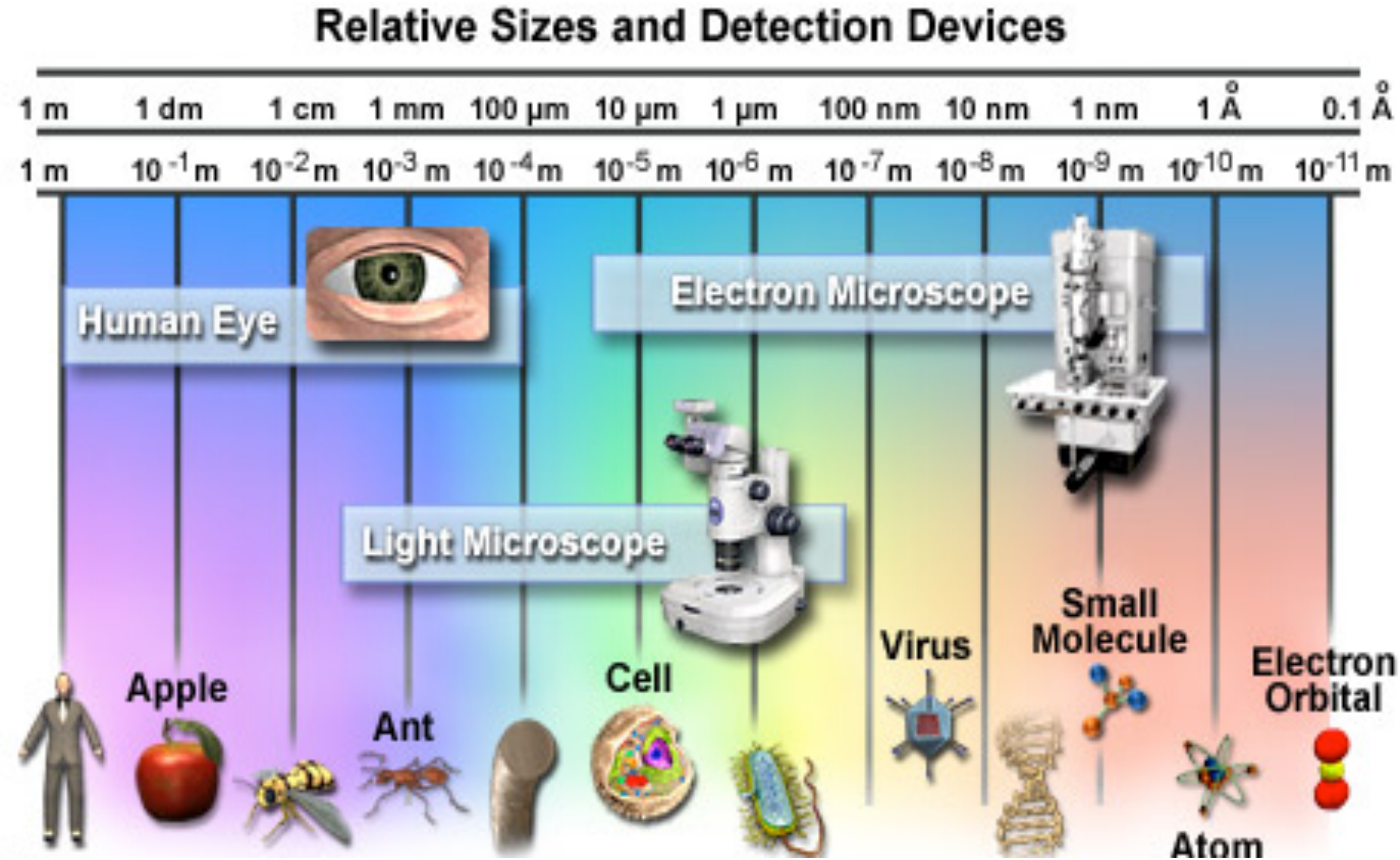
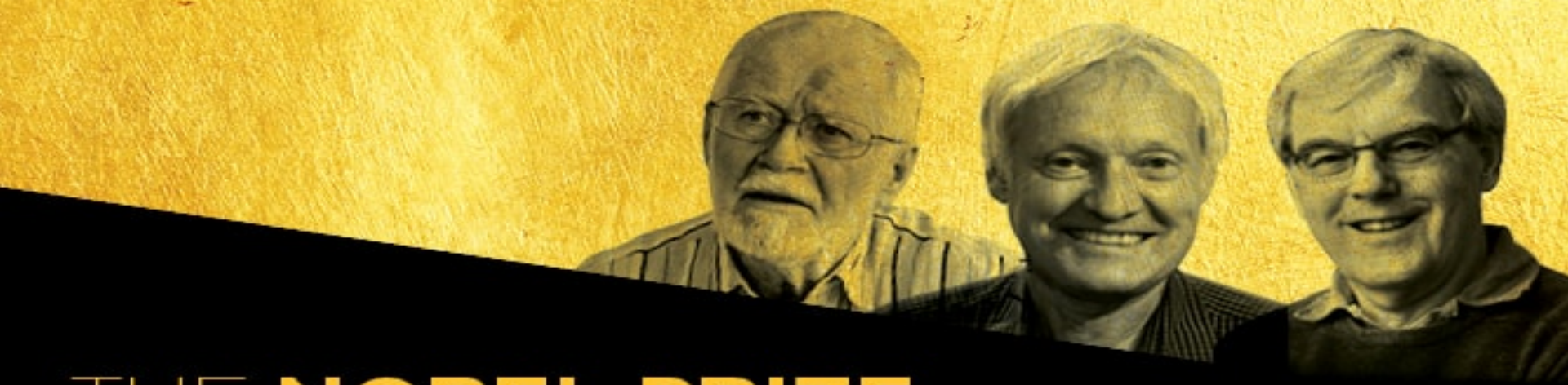
Vidět znamená věřit

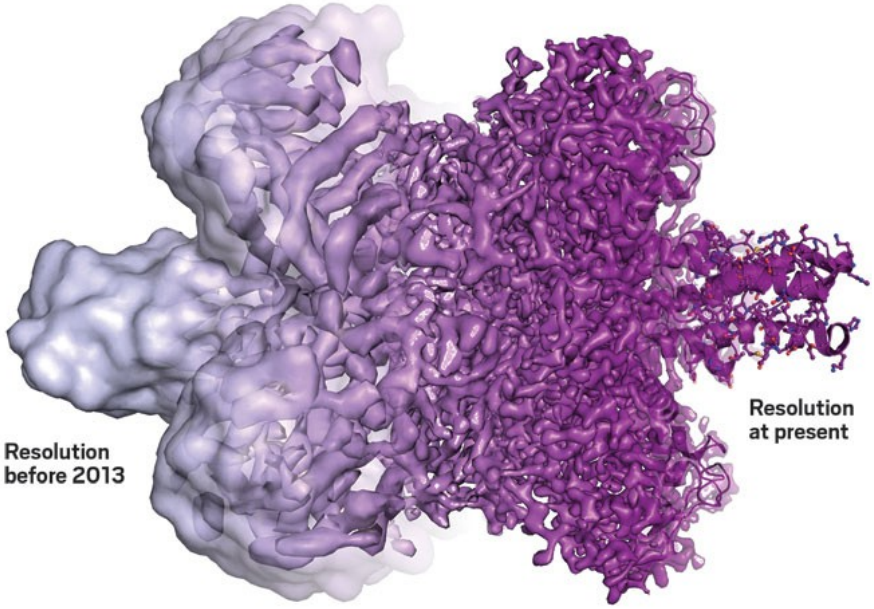


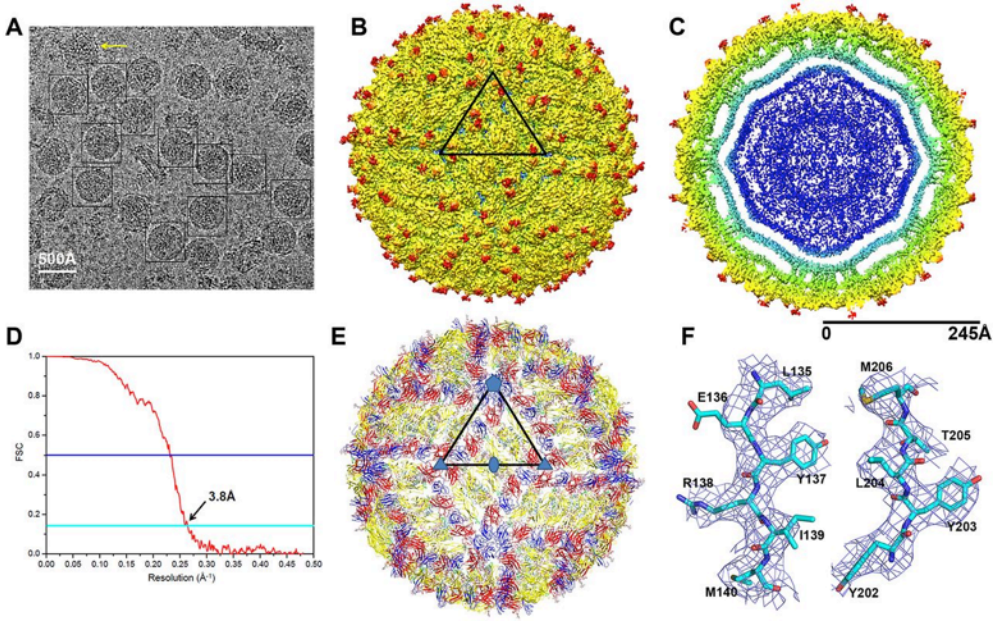


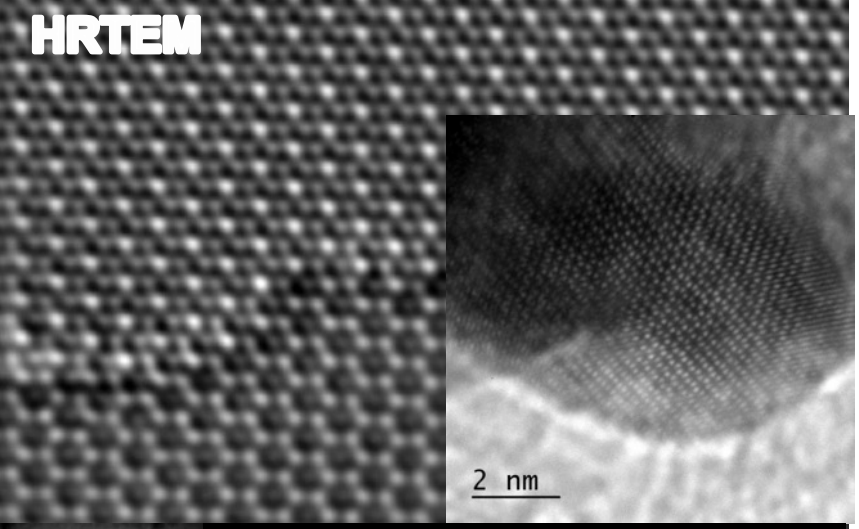
THE NOBEL PRIZE IN CHEMISTRY 2017 GOES TO

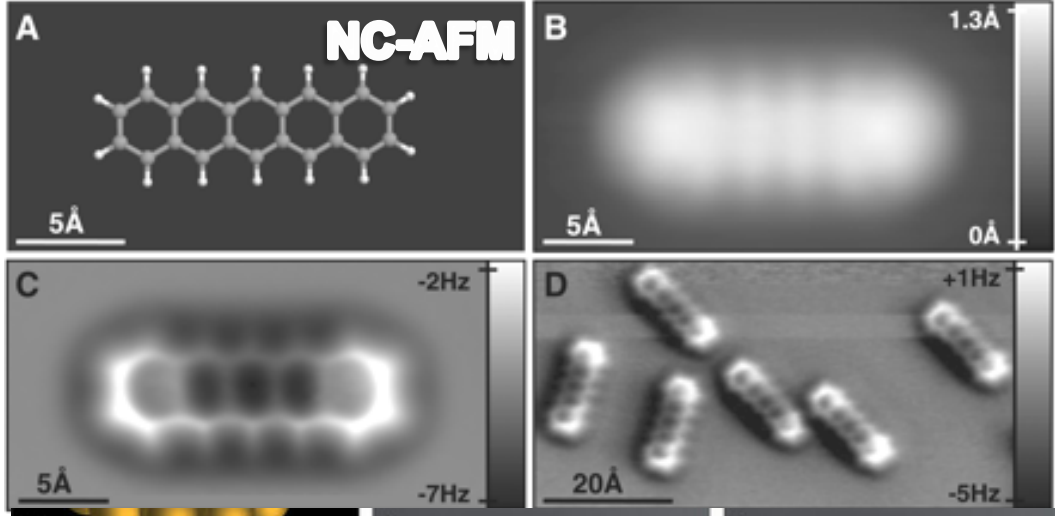
Jacques Dubochet, Joachim Frank, and Richard Henderson

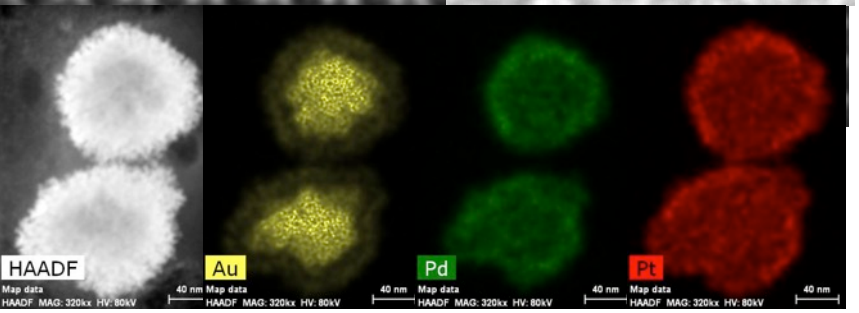
za rozvoj kryo-elektronové mikroskopie

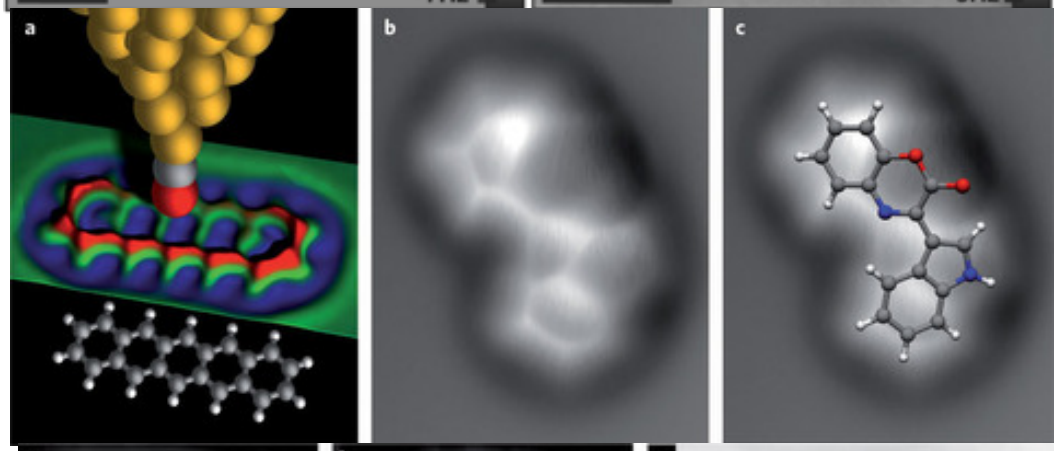


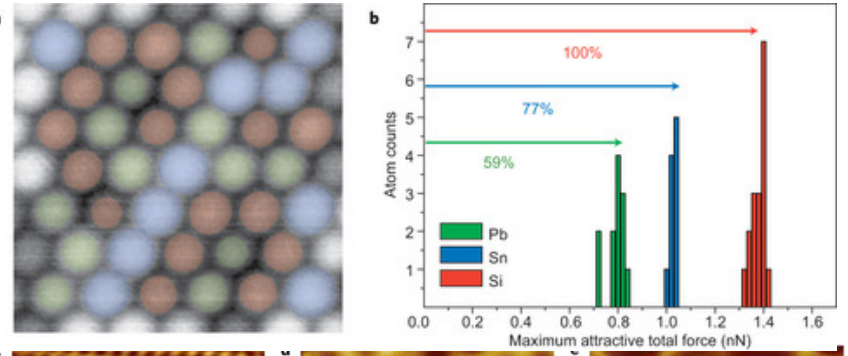


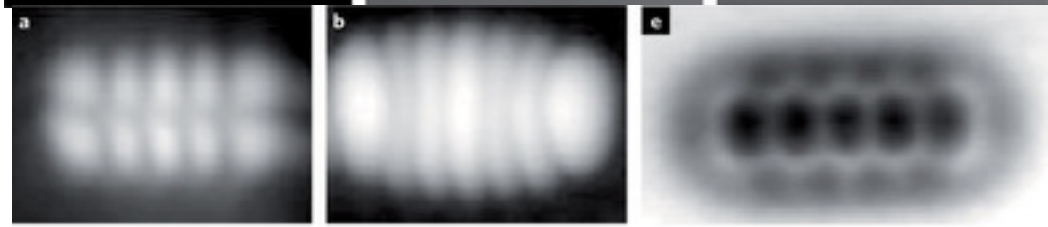

HRTEM
2 nm

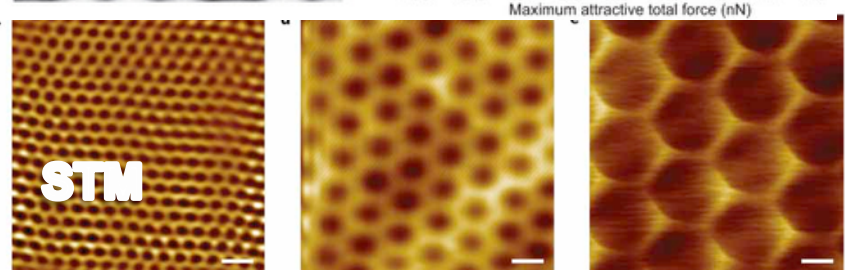

A
NC-AFM
5Å
B
1.3Å
5Å
0Å
C
-2Hz
5Å
-7Hz
D
+1Hz
20Å
-5Hz

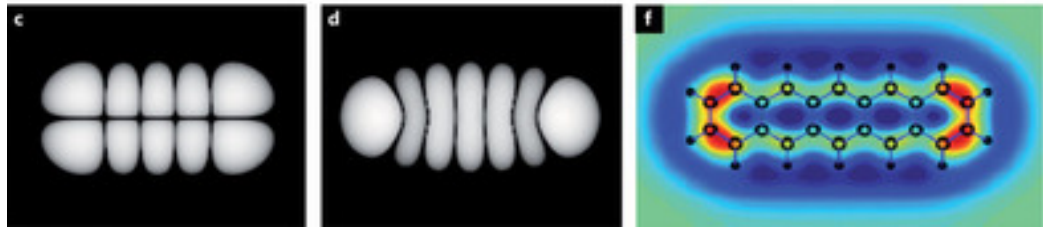

HAADF
Au
Pd
Pt
Map data
HAADF MAG: 320kx HV: 80kV
40 nm


a
b
c


b
100%
77%
59%
Atom counts
Pb
Sn
Si
Maximum attractive total force (nN)


a
b
e
HOMO
LUMO
Atomic structure


STM


c
d
f

2D vs 3D

Zjednodušeně řečeno, **dimenze** označuje počet parametrů, kterými jsme schopni každý vektor daného vektorového prostoru jednoznačně popsat.

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Grafit – forma uhlíku

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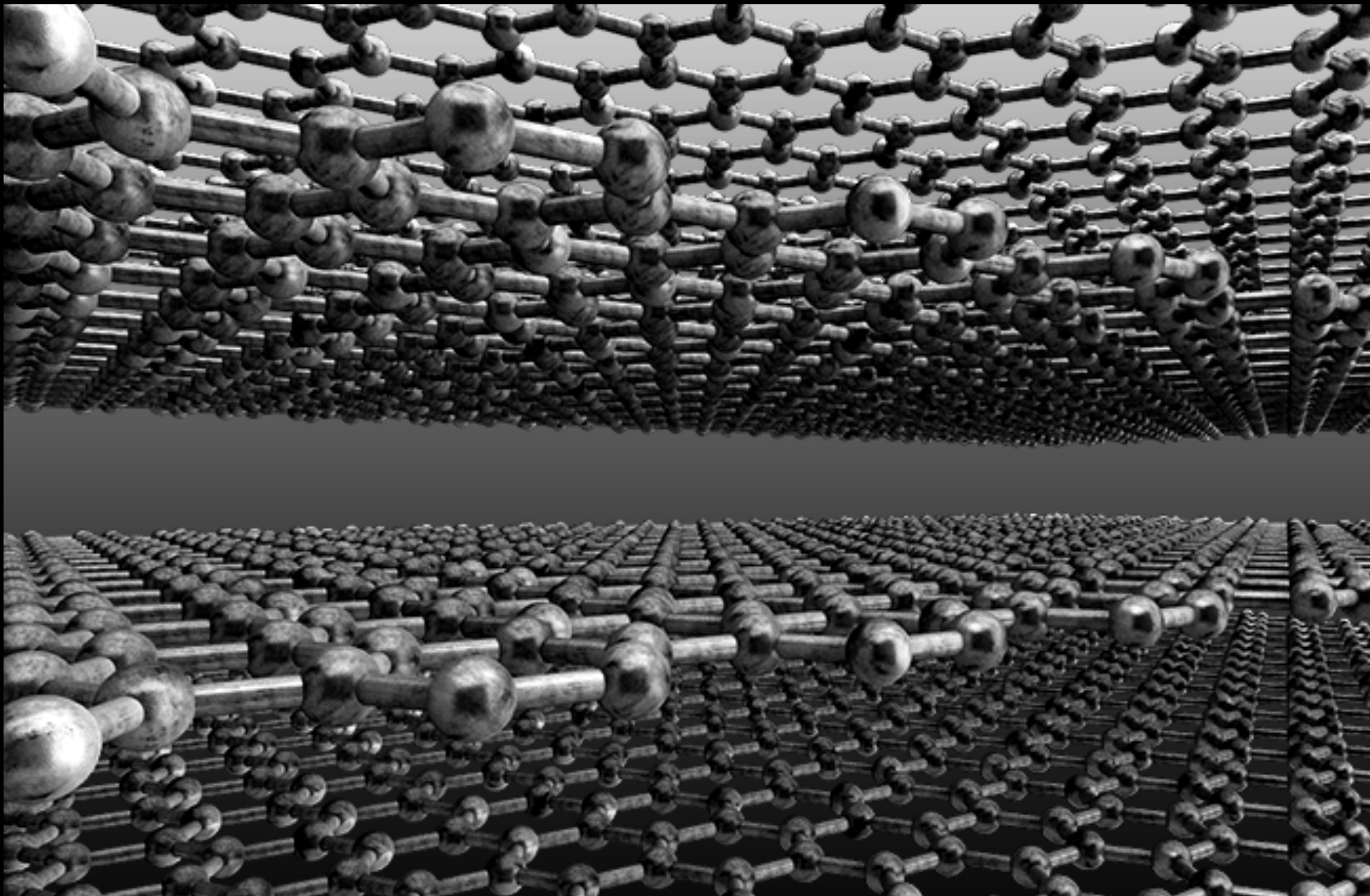
Grafit má vrstevnatou strukturu



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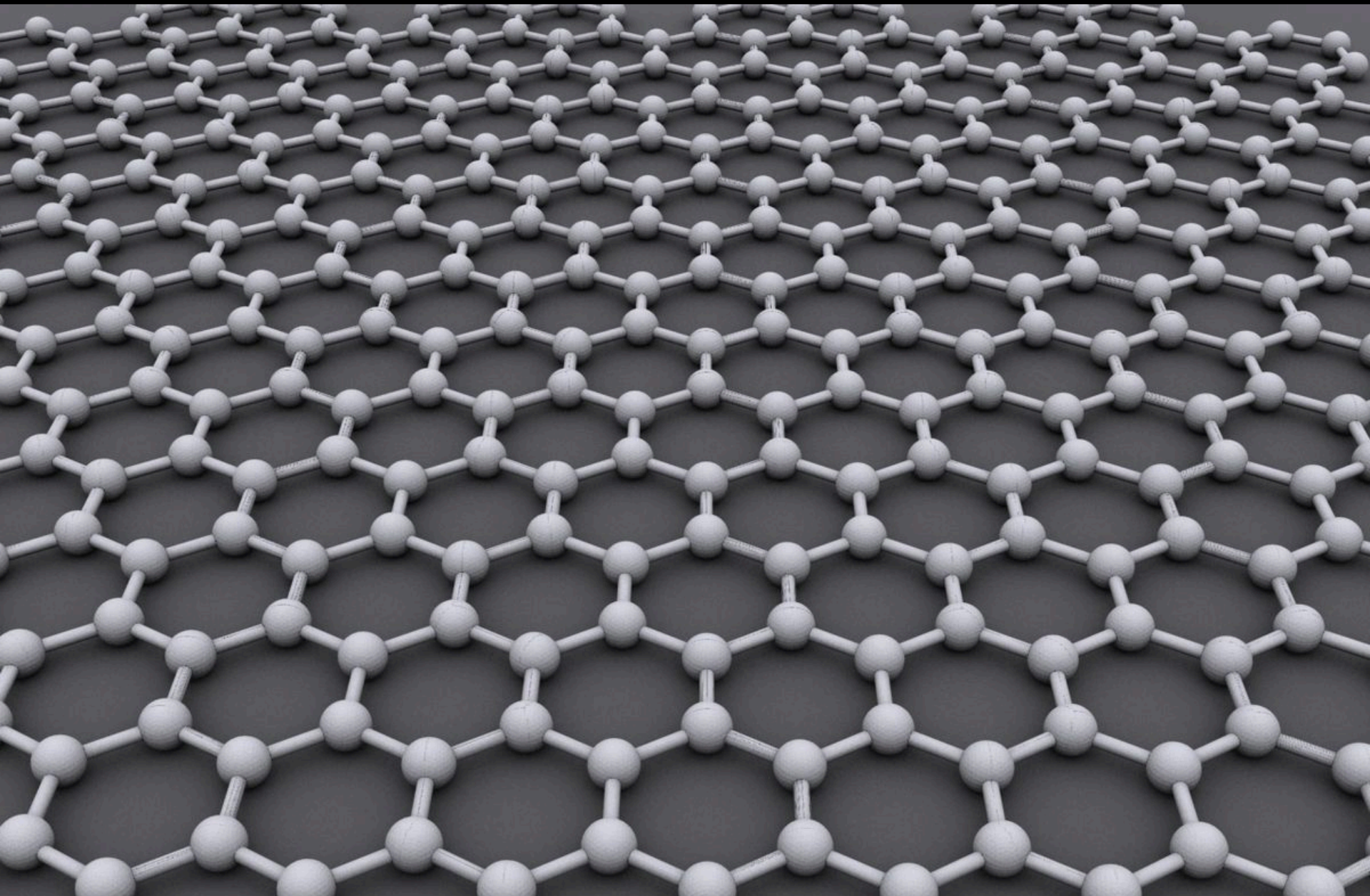
Jedna vrstva grafitu = grafen



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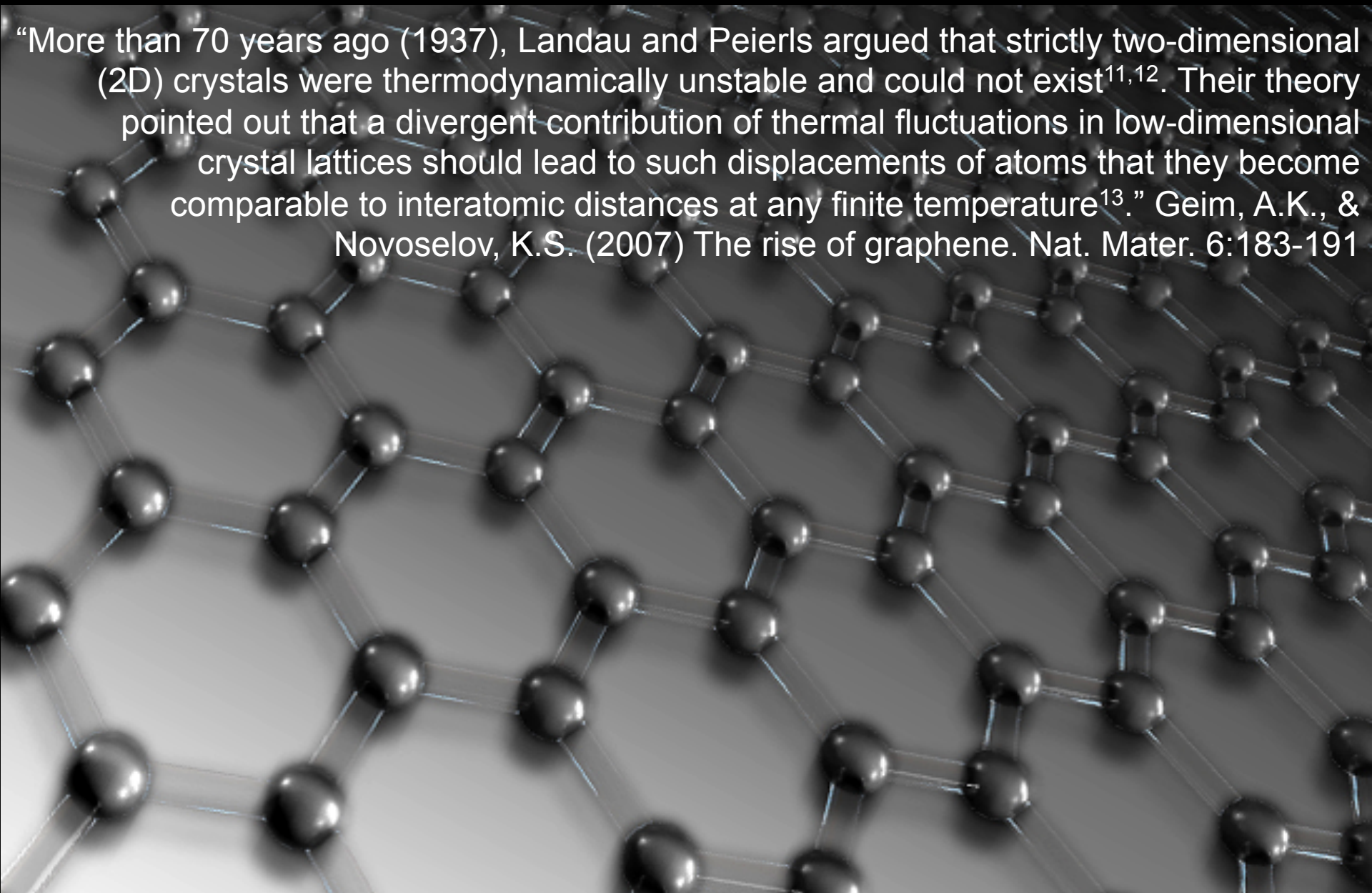
Materiál co neměl existovat

"More than 70 years ago (1937), Landau and Peierls argued that strictly two-dimensional (2D) crystals were thermodynamically unstable and could not exist[11,12]. Their theory pointed out that a divergent contribution of thermal fluctuations in low-dimensional crystal lattices should lead to such displacements of atoms that they become comparable to interatomic distances at any finite temperature[13]." Geim, A.K., & Novoselov, K.S. (2007) The rise of graphene. Nat. Mater. 6:183-191



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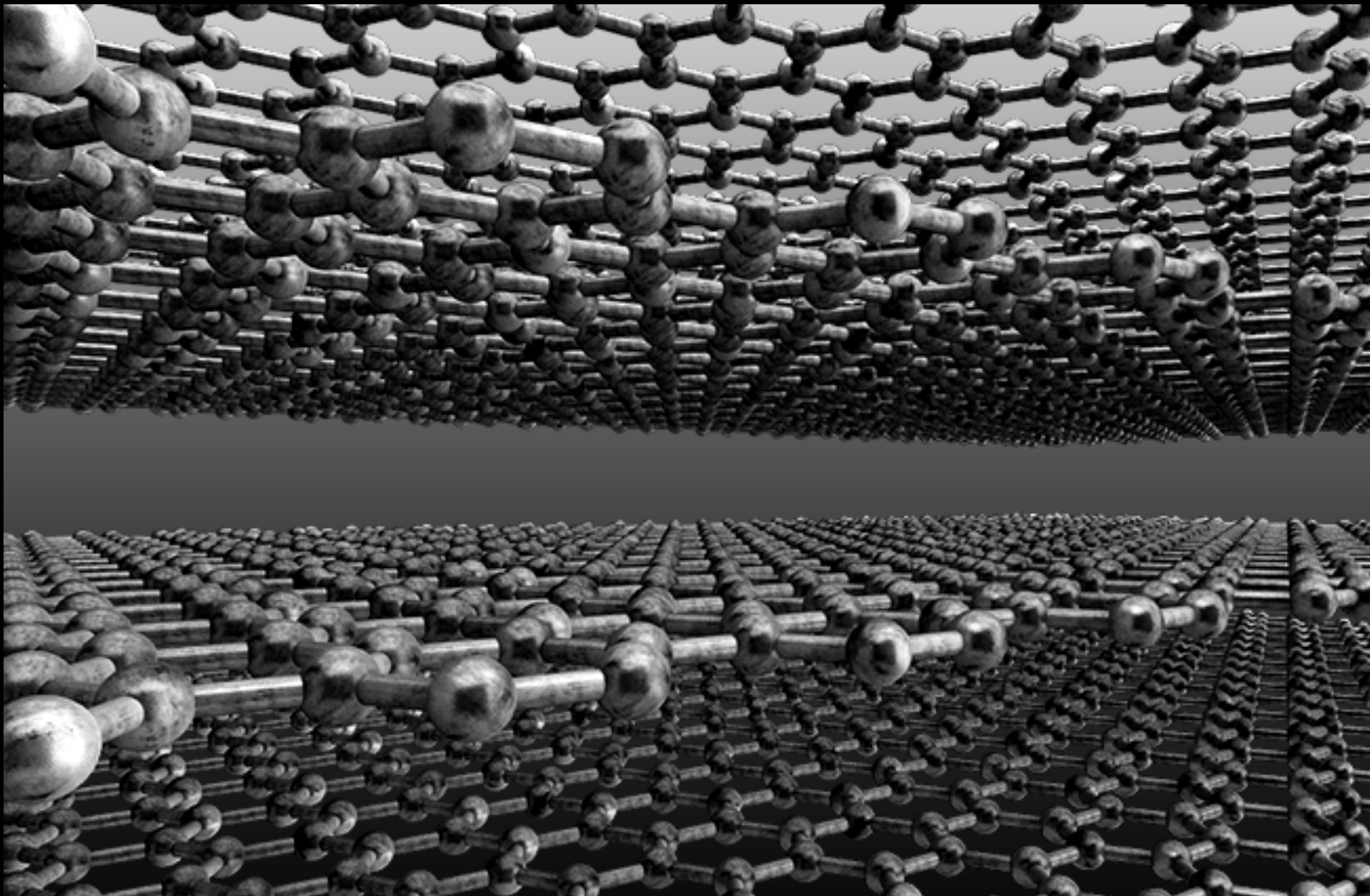
Kolik vrstev?



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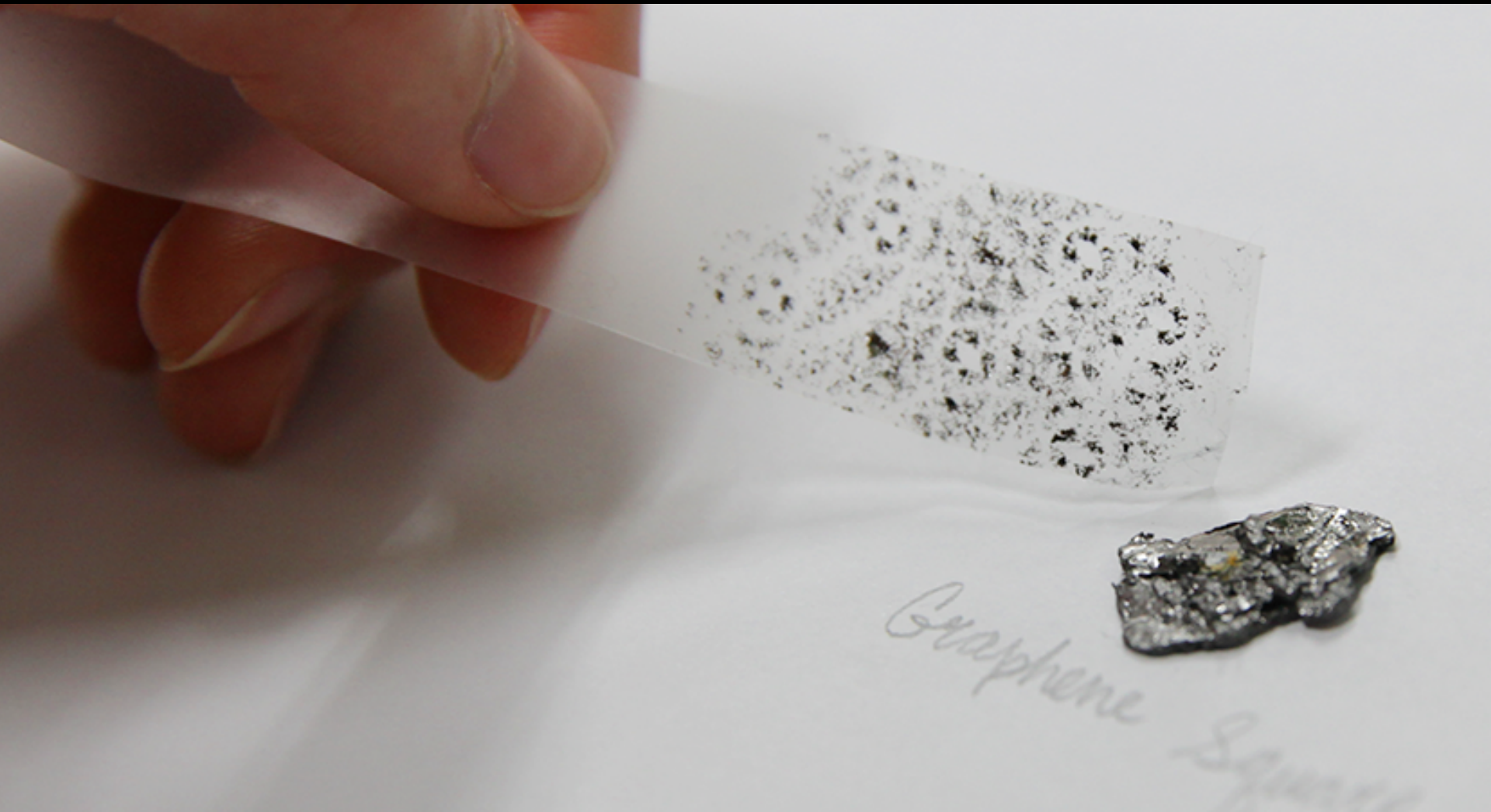
Materiál co neměl existovat

… přesto byl připraven v roce 2004 mechanickou exfoliací grafitu



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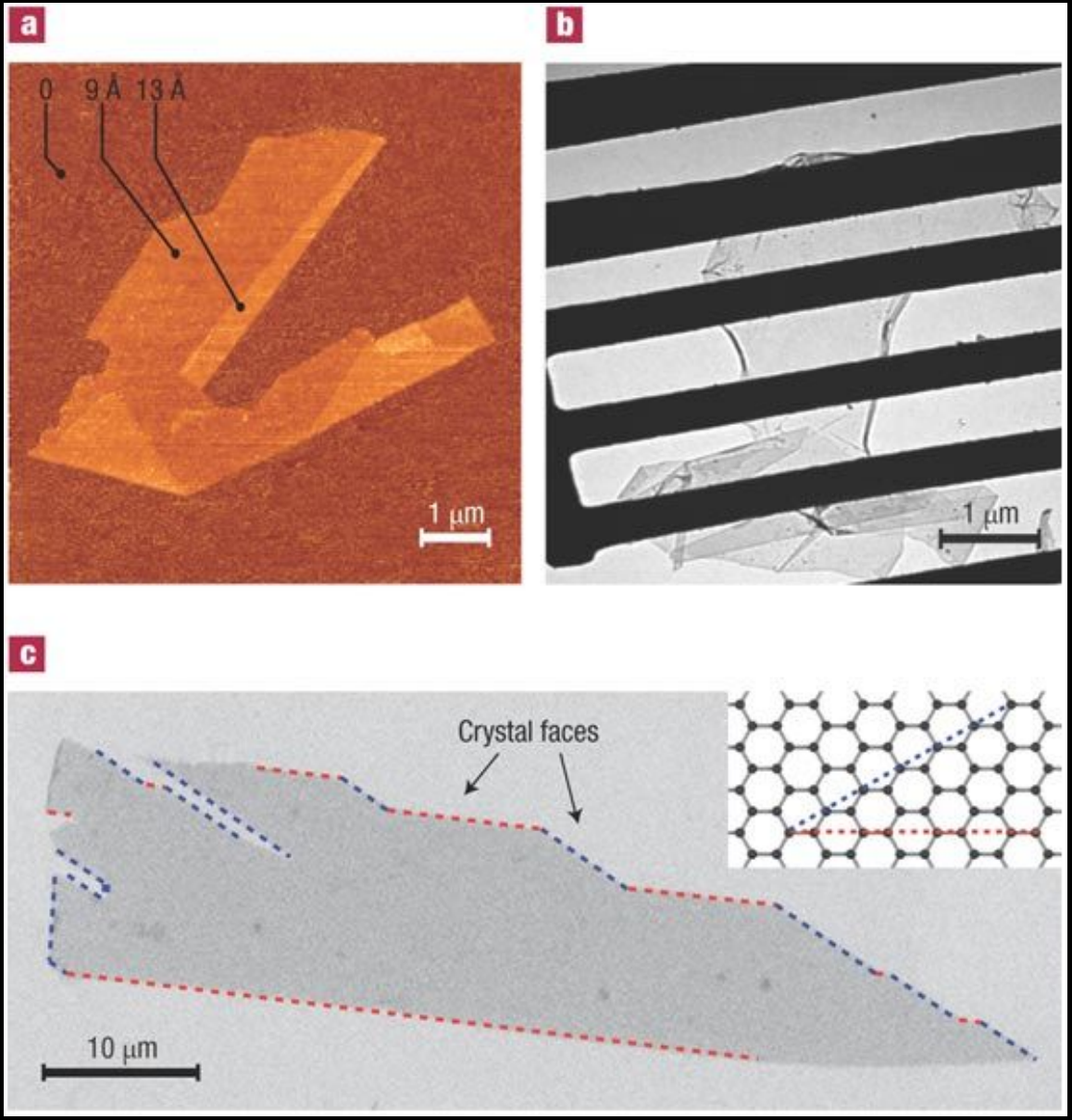
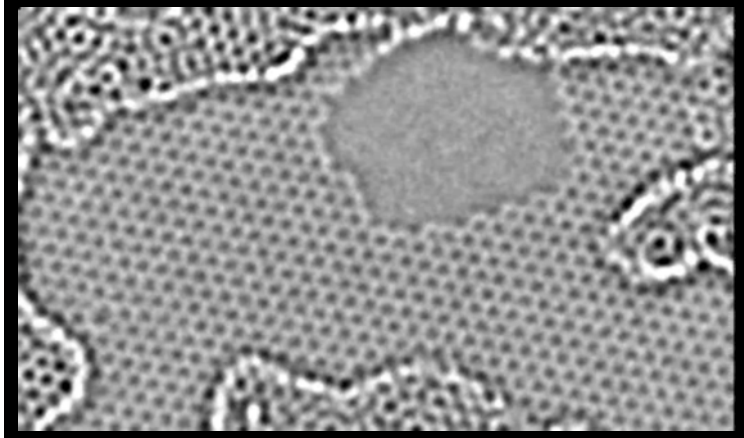
Jak opravdu grafen vypadá?



Atomově tenký krystal: nejtenčí materiál, jaký můžeme vidět

A. K. Geim & K. S. Novoselov
Nature Materials 6, 183 (2007)



Zettl grp. Berkley, USA

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Nobelova cena za fyziku

byla v roce 2010 udělena společně Andre Geimovi a Konstantinu Novoselovovi ”za průlomové experimenty týkající se 2D materiálu grafenu"

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Andre Geim je i Ig nobelista

V roce 2000 A Geim získal také Ig Nobelovu cenu za využití magnetického pole pro levitaci živého organismu žáby. Prof. Geim je dosud jediným (indviduálním) nositelem prestižního vědeckého ocenění i jeho parodie.

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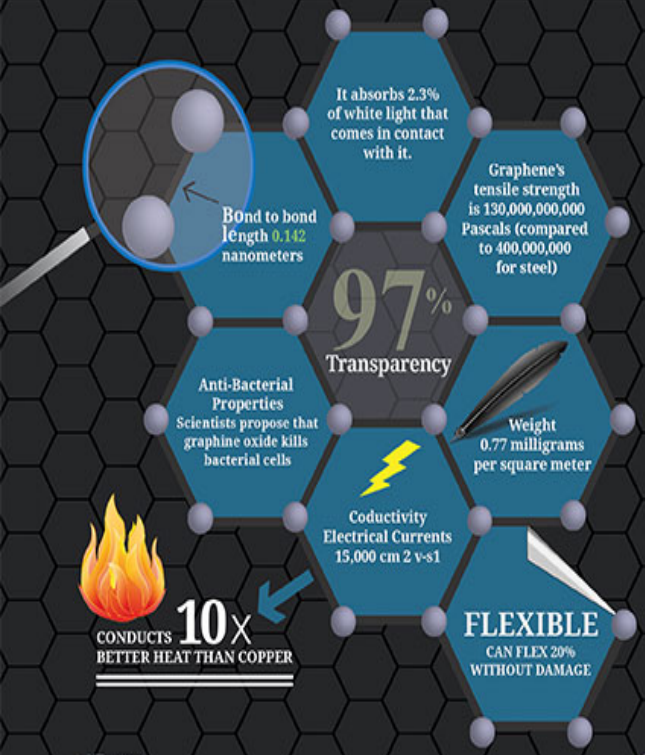
K čemu může grafen být?

GRAPHENE

The Strongest Known Material To Man

The next time you write with a pencil, consider that you have one of the world's most powerful substances at your fingertips. Graphene is a single atomic layer of graphite, the same stuff used in pencil lead. Often described as having the shape of chicken wire, the atomic material is on track to change the technology industry. The material is a one-atom-thick sheet of carbon and almost completely transparent. Graphene is also considered the world's thinnest material while being conductive, transparent and flexible.

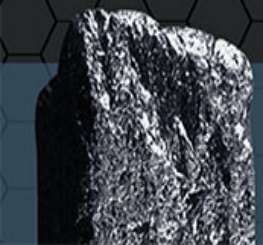


GLOBAL GRAPHITE PRODUCTION

$12 US Billion
Market Graphite Demand

SUPPLY FOR GRAPHITE IS GROUPED INTO TWO FORM CATAGORIES

40% FLAKE FORM
60% AMORPHOUS



Graphite demand is expected to increase by +50% by 2020. Demand from high tech applications is projected to be dramatic.

A sheet as thick as saran wrap would take the weight of an elephant standing on a tip of a pencil to pucture it.

CURRENT MARKETPLACE

The graphene market is still small and driven by research related demand. By 2018, graphene products are predicted to bring in over 100 million in revenue. Graphene products will have a range of applications including RFID, packaging, sensors and super capacitors, among others.

FIRST GRAPHENE PRODUCTS

Vorbeck Materials graphene ink was used in the first graphene product in 2012.

Head announced their new range of graphene tennis rackets in early 2013.

FIRST GRAPHENE IPO

Applied Graphene Materials went on the London Stock Exchange in November 2013. The high specification graphene business has a current market cap of 108 million.

POTENTIAL APPLICATIONS

Materials

Graphene may revolutionize the medical industry with Graphene based sensors for single molecule detection and bio-devices.

Since Graphene is one of the strongest materials on earth, it can make stronger and lighter planes, trains and automobiles.

Scientists at the University of Manchester believe graphene can be combined with latex to form ultra thin and tough condoms.

Electronics

One of the first graphene applications will be touchscreens. Given the flexibility of graphene, you'll see the rise of consumer electronics with flexible screens.

Super capacitors and Li-Ion batteries. Using graphene in batteries may also improve charging and battery power by ten times.

Transistors. IBM has already developed a 280GHz 40nm graphene transistor.

Graphene vs. Silicon

Higher electrical conductivity

Fewer atoms per transistor - Smaller transistors switch faster and use less power than larger ones. Silicon can support transistors as low as 10 nanometers consisting of a couple hundred silicon atoms. Graphene only has a six atom wide transistor.

6 atom wide transitor

Silicon 0.7 V vs. Graphene 0.2 V

Lower "band gap." This basically means how much voltage you need to make the transistor work. For silicon, the voltage is as low as 0.7V. For graphene, it can get down to about 0.2 V

Sources: graphene-info.com, grapheneа.com, visualcapitalist.com, idtechx.com, graphenetracker.com

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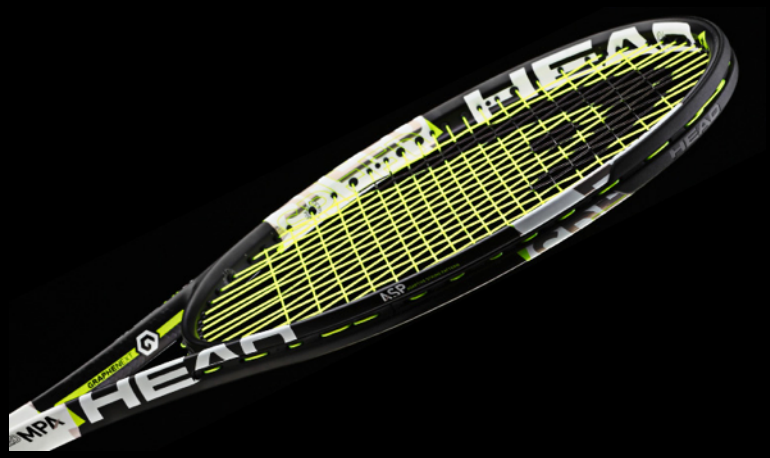
K čemu už grafen je?



GRAPHENE FLAGSHIP

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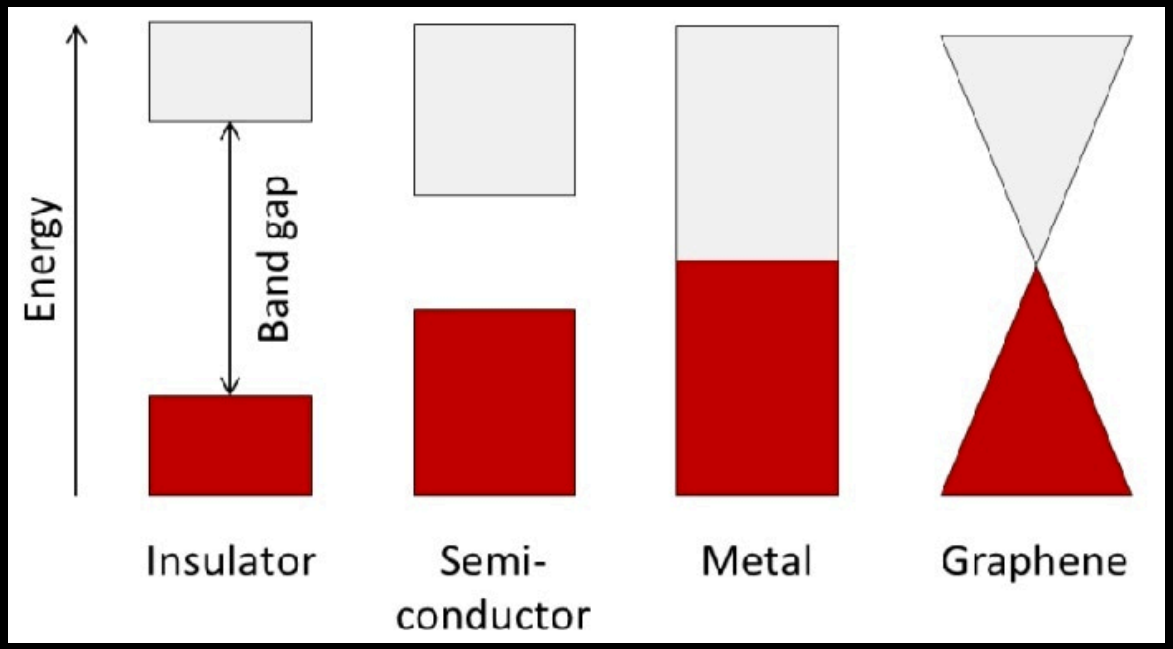
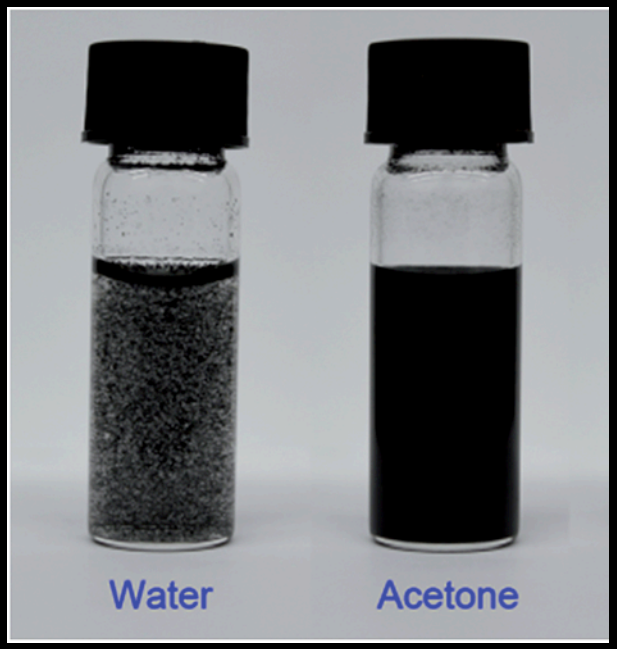
Lze ho ještě vylepšit?

Grafen není polovodič



Grafen nerad vodu



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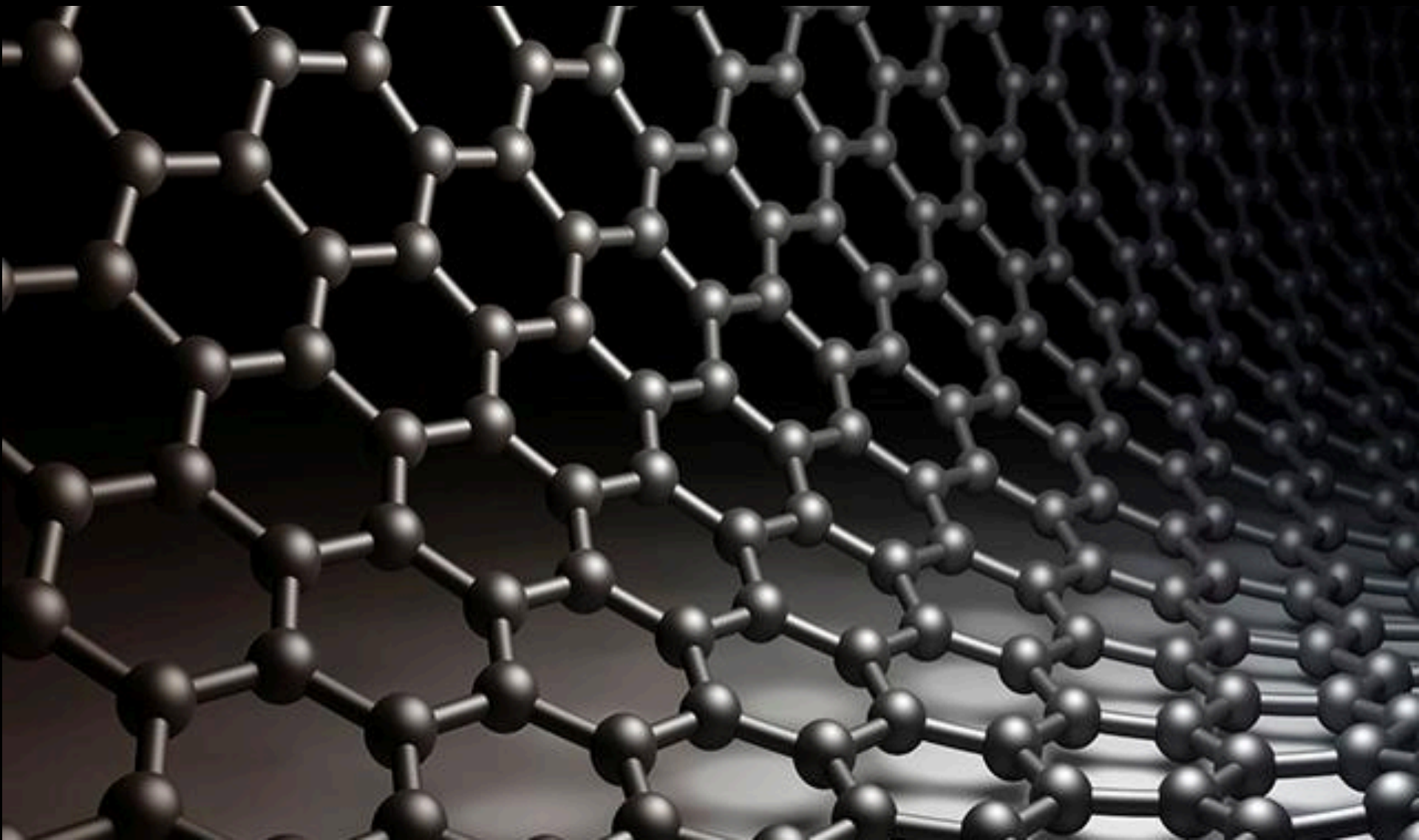
Jak ho vylepšit?

Grafen je nereaktivní



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Jak ho vylepšit?

Grafen je nereaktivní

Brutální oxidace

Brodie: HNO_3, $KClO_3$

Hummers: $KMnO_4$, H_2SO_4, $NaNO_3$

Studená plazma

Fluorace

F_2, XeF_2

Další (malé výtěžky a pokrytí)

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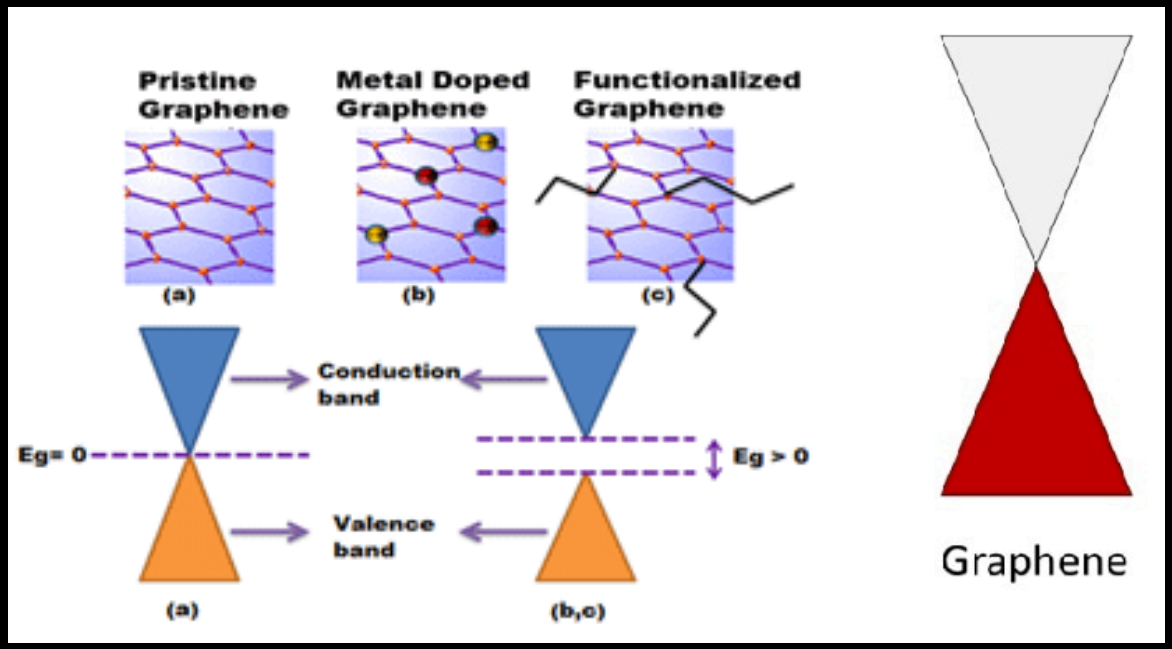
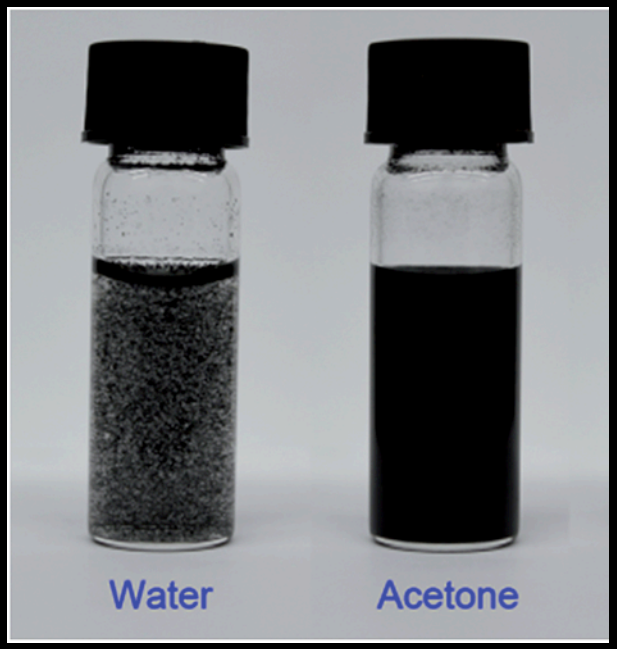
.. ale já chci!

My chceme grafenový polovodič!



Ať má rád vodu!



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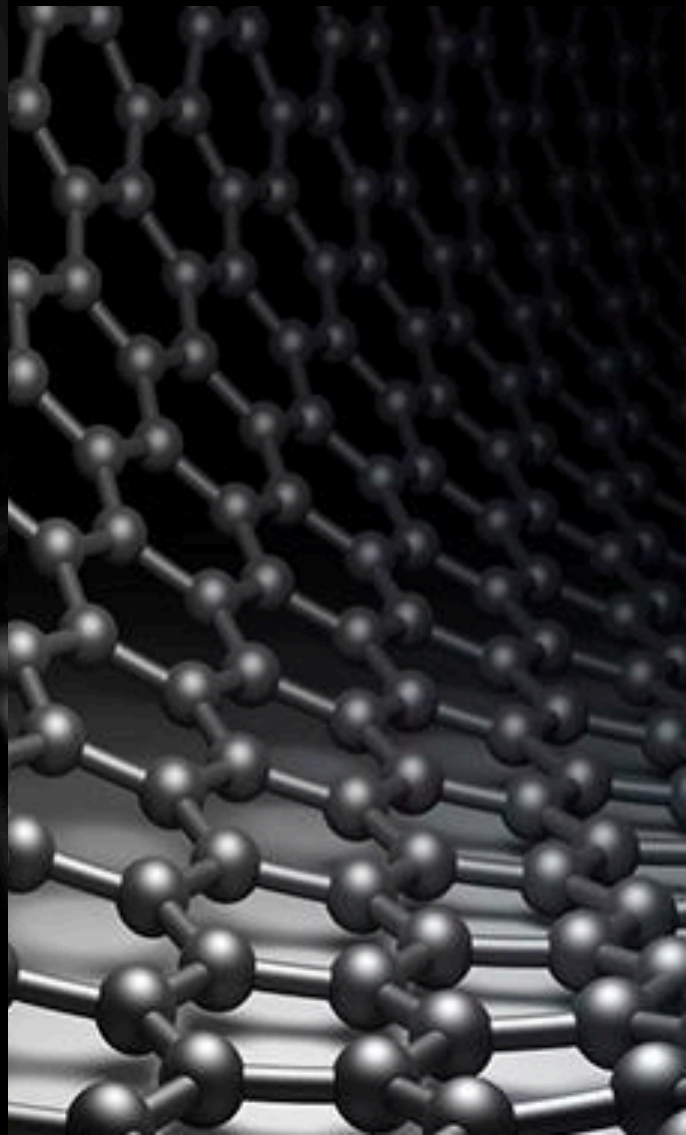
Není jiná cesta?

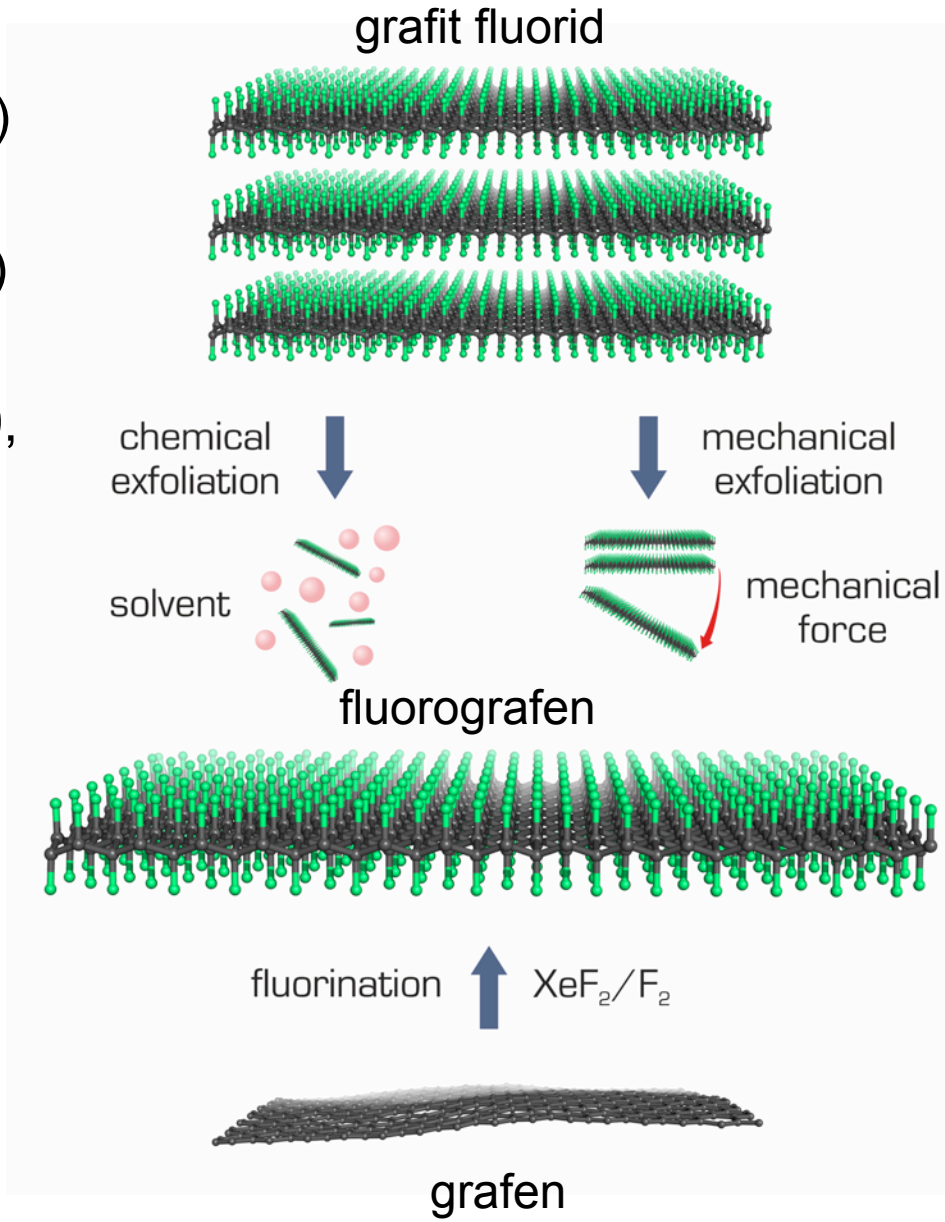


Fluorografen

Mechanická exfoliace grafit fluoridu
Nair RR et al. Small 6, 2877 (2010)

Chemická exfoliace grafit fluoridu
Zbořil R et al. Small 6, 2885 (2010)

Fluorace grafenu
Robinson JT et al. Nano Letters 10, 3001 (2010)
Cheng SH et al. PRB 81, 205435 (2010)



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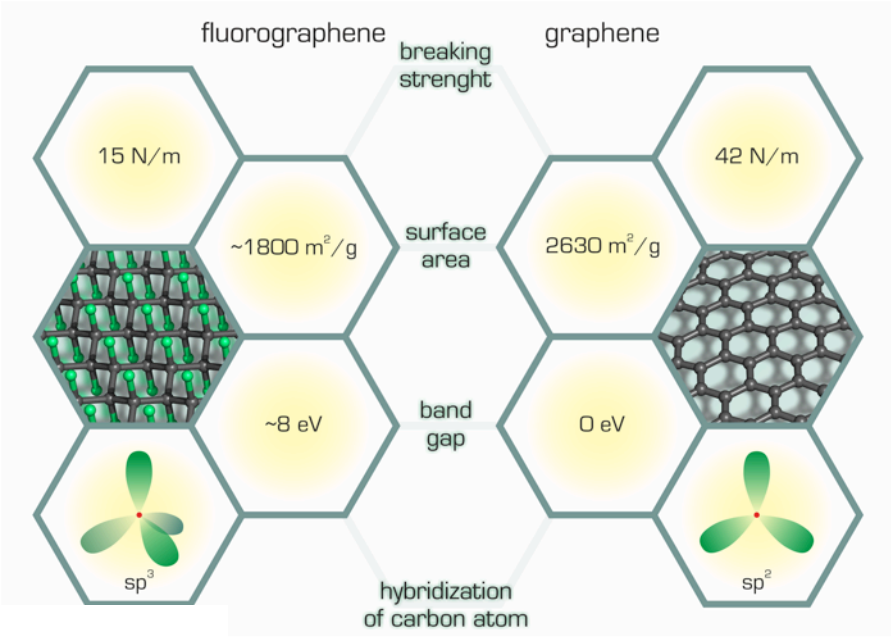
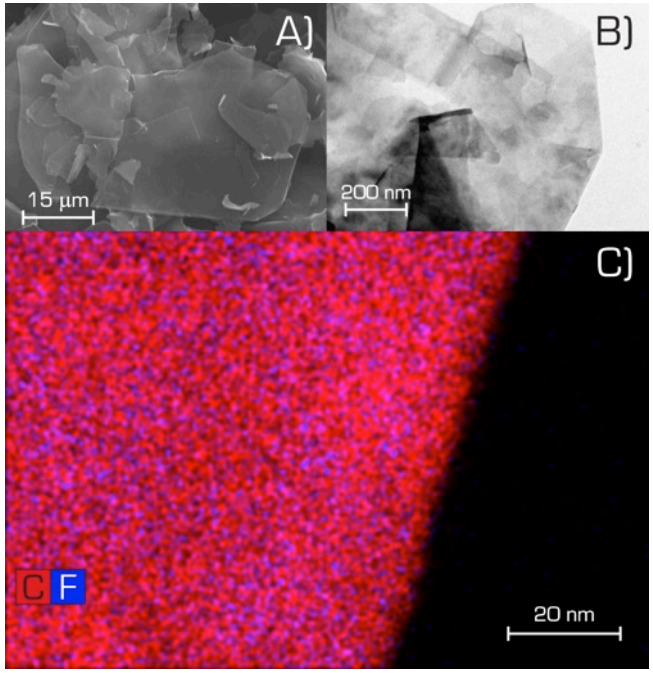
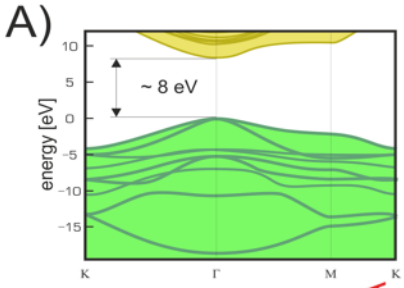
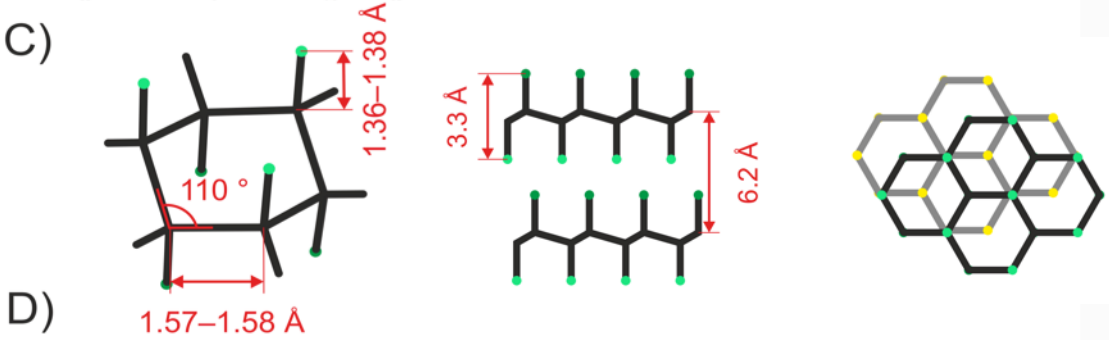
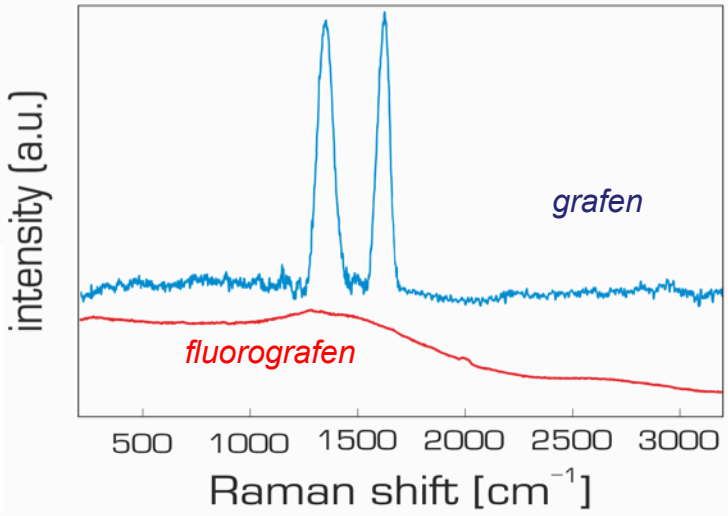
Vlastnosti fluorografenu











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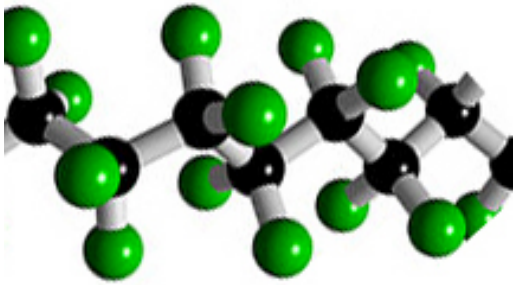
Je to analog Teflonu?

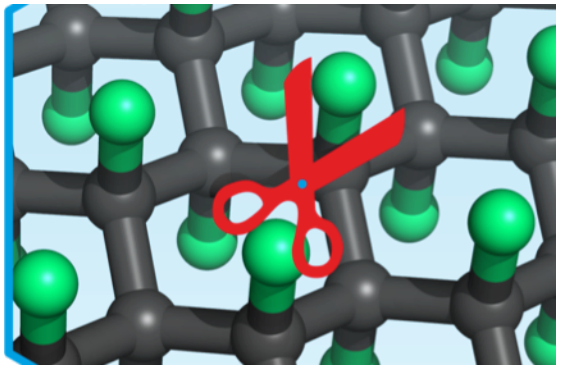
Fluorinated graphene

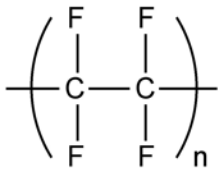
Fluorographene: A Two-Dimensional Counterpart of Teflon

Rahul R. Nair, Wencai Ren, Rashid Jalil, Ibtsam Riaz, Vasyl G. Kravets, Liam Britnell, Peter Blake, Fredrik Schedin, Alexander S. Mayorov, Shengjun Yuan, Mikhail I. Katsnelson, Hui-Ming Cheng, Wlodek Strupinski, Lyubov G. Bulusheva, Alexander V. Okotrub, Irina V. Grigorieva, Alexander N. Grigorenko, Kostya S. Novoselov,* and Andre K. Geim**

***A** stoichiometric derivative of graphene with a fluorine atom attached to each carbon is reported. Raman, optical, structural, micromechanical, and transport studies show that the material is qualitatively different from the known graphene-based nonstoichiometric derivatives. Fluorographene is a high-quality insulator (resistivity > 10^2 Ω) with an optical gap of 3 eV. It inherits the mechanical strength of graphene, exhibiting a Young's modulus of 100 N m^{-1} and sustaining strains of 15%. Fluorographene is inert and stable up to 400 °C even in air, similar to Teflon.*



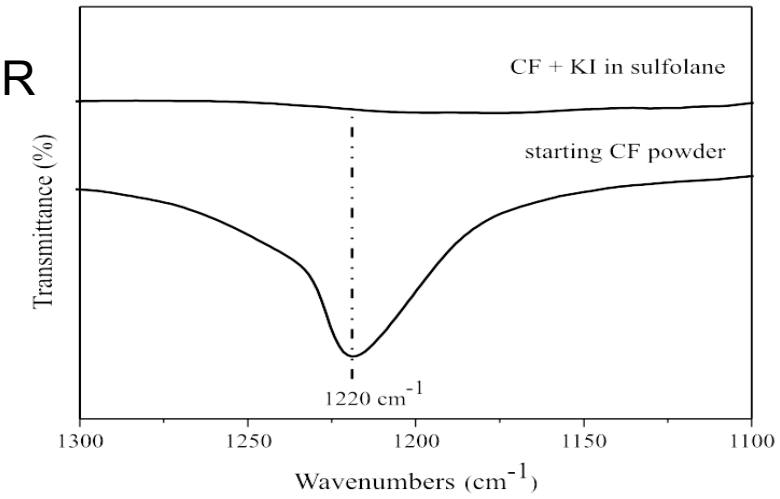


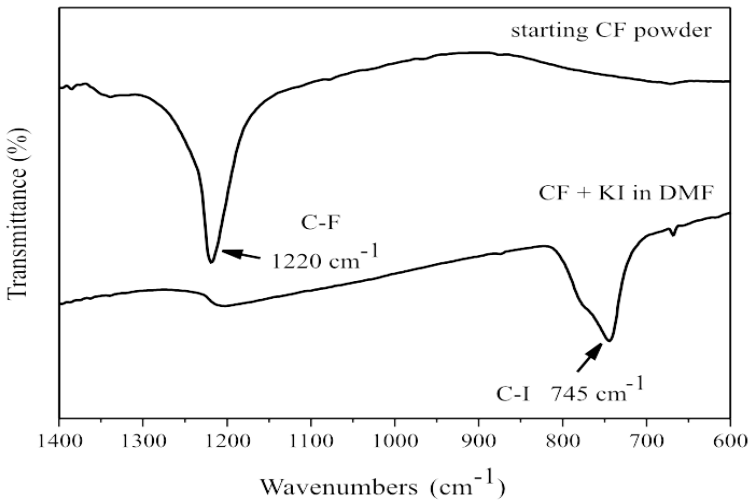


Nair et al., Small 6, 2878, 2010

$$CF + KI \rightarrow KF + [CI]\ ;\ [CI] \rightarrow C + \tfrac{1}{2} I_2 \quad (180\ ^\circ C)$$

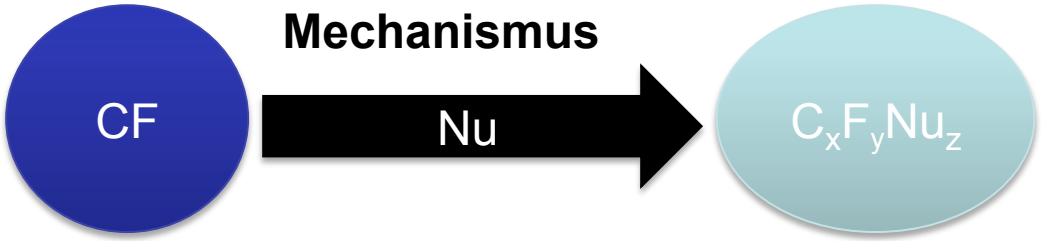
IR



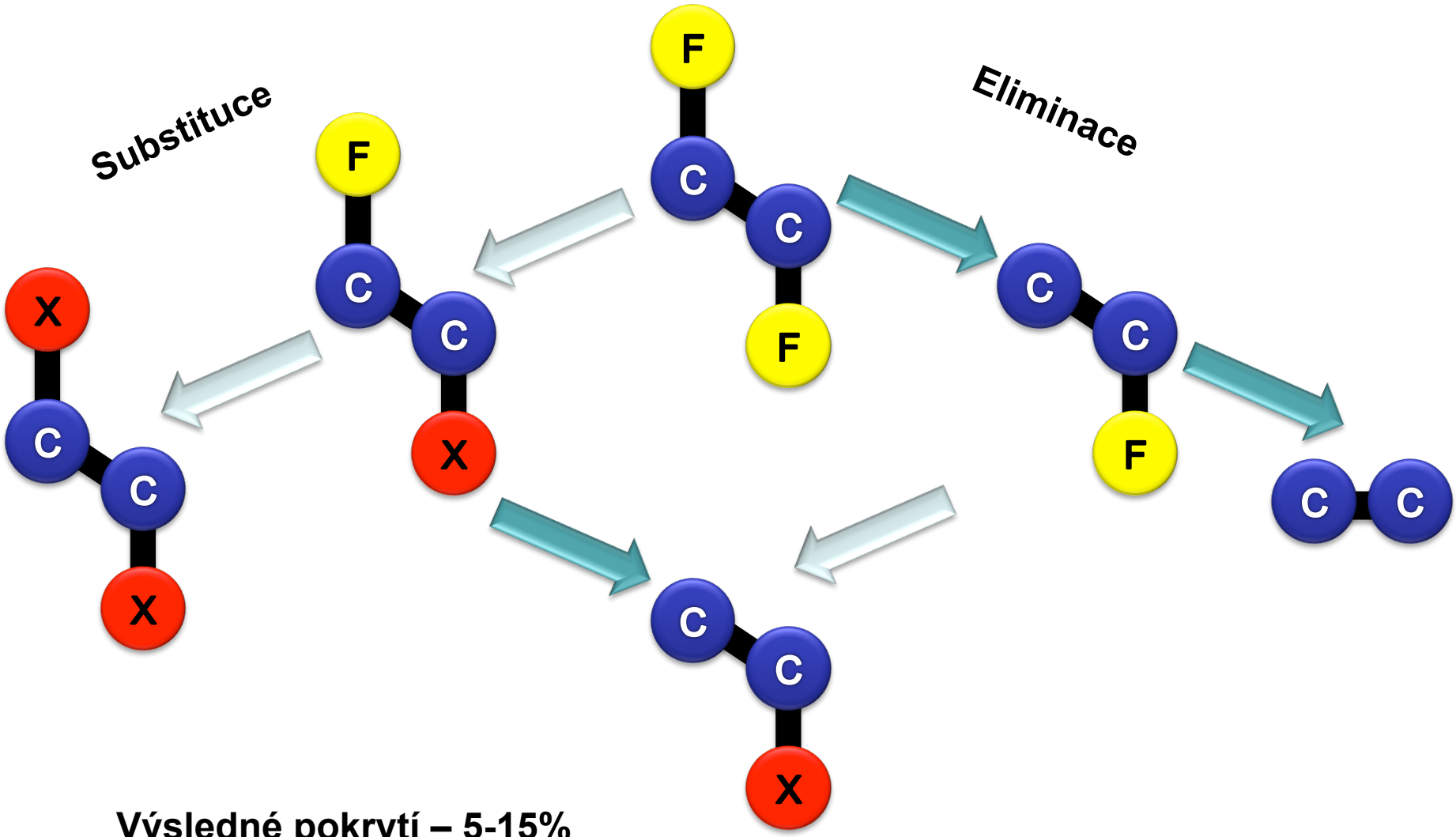


Zbořil et al., Small 6, 2885, 2010

Fluorografen reaguje velmi snadno např. s NaOH



Reaktivita fluorografenu



Výsledné pokrytí – 5-15%

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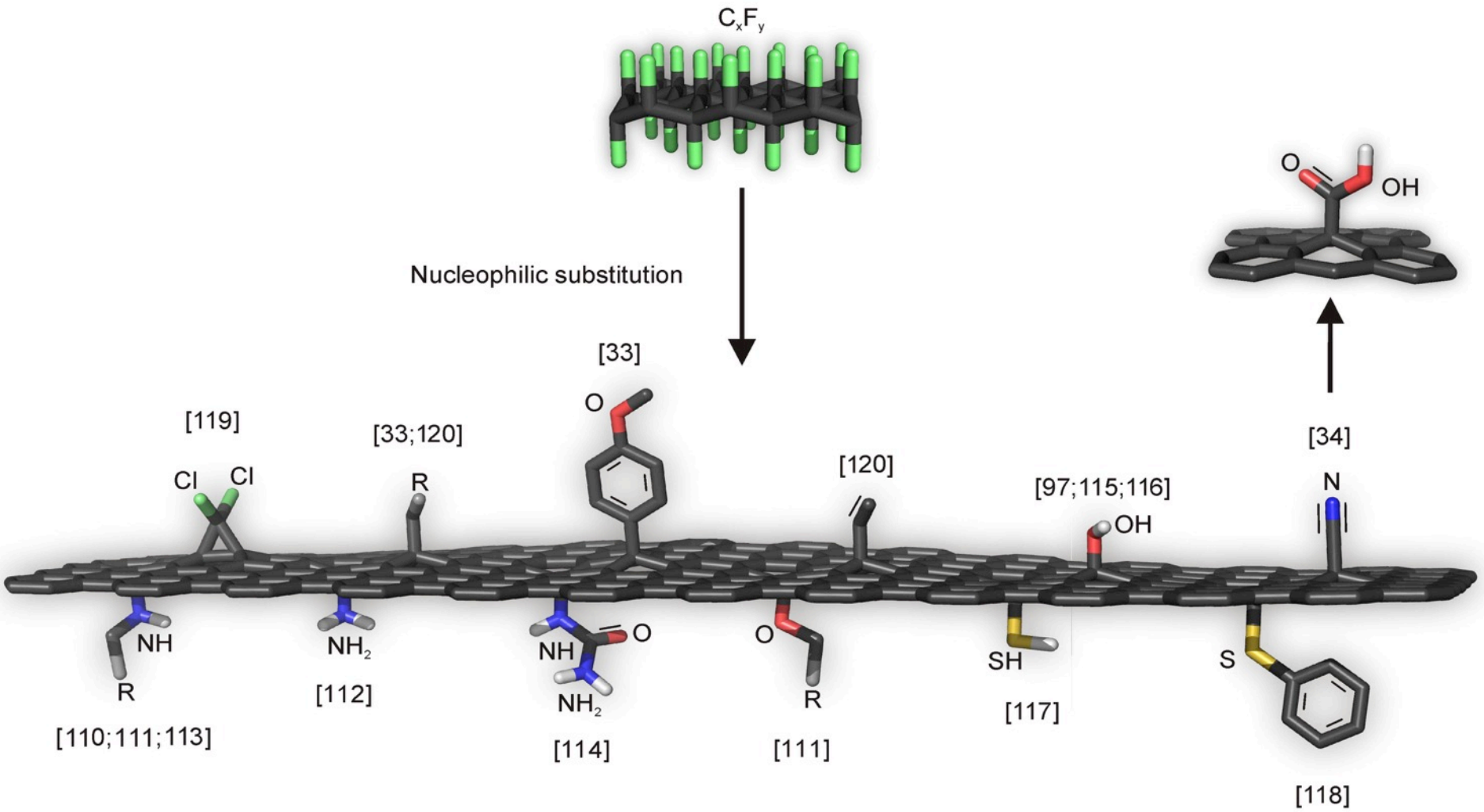
Co lze z fluorografenu vyrobit?



Appl. Mater. Today, 9, 60-70, 2017

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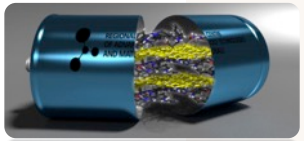
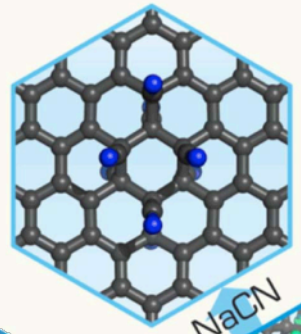
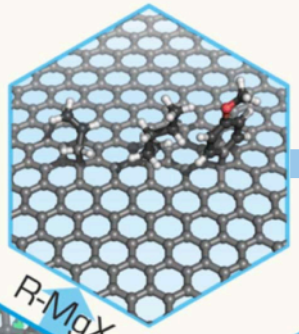
K čemu to bude?

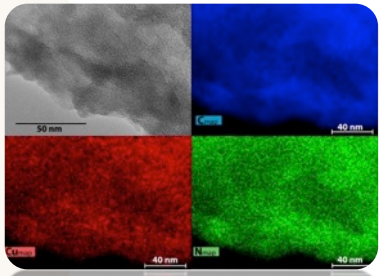
ACS Nano. **2017**, 11, 2982

Chem. Mater. **2017**, 29, 926

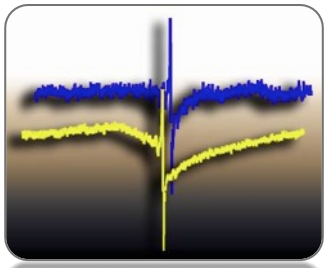


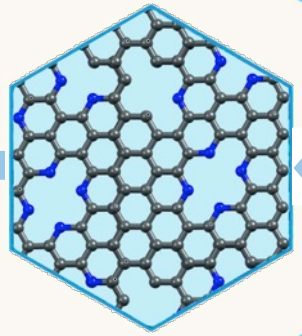


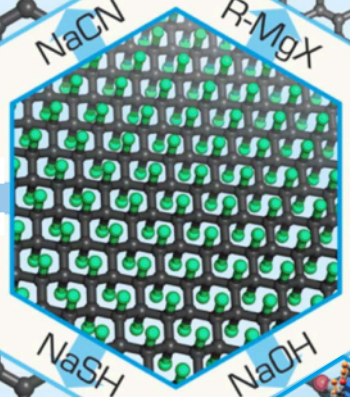


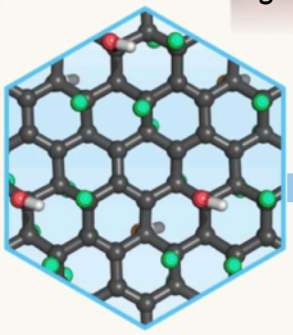


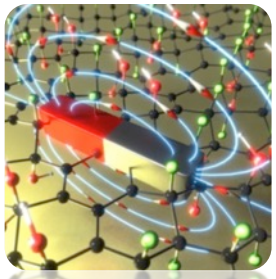
Single metal atom catalysts





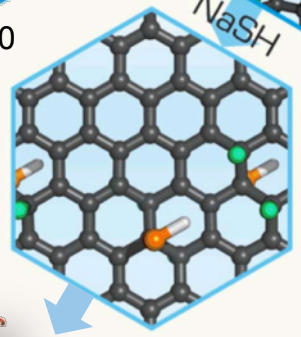


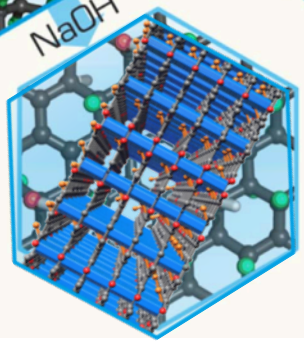


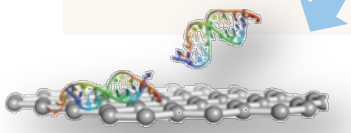


Small **2015**, 11 , 3790

Nature Comm. **2017**, 8, 14525







J. Phys. Chem. Lett. **2015**, 6, 1430

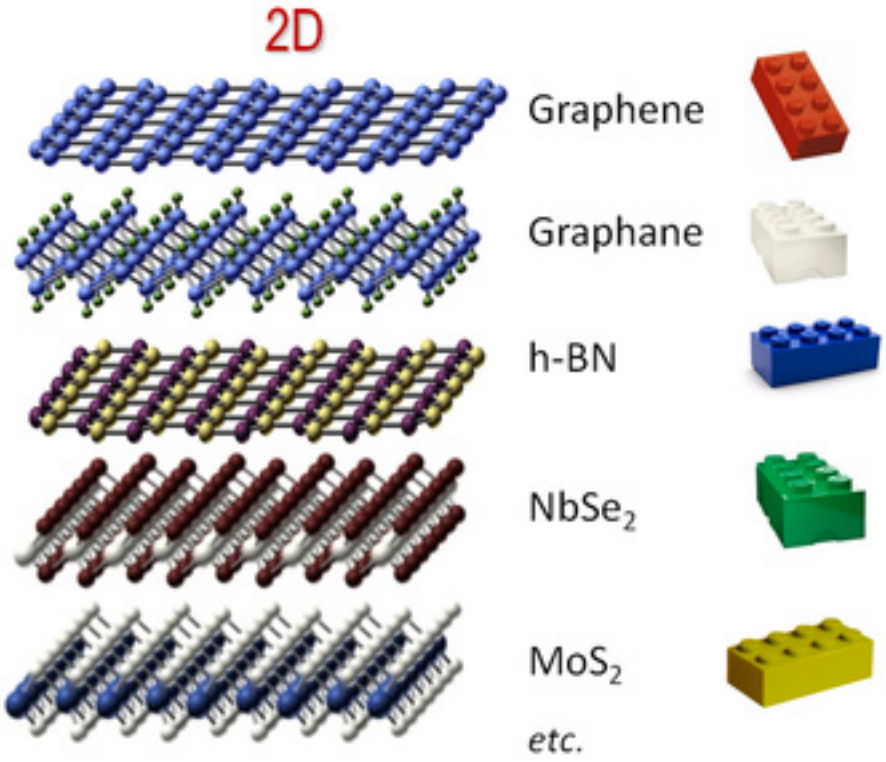
Angew. Chem. Int. Ed., **2016**, 55, 1178

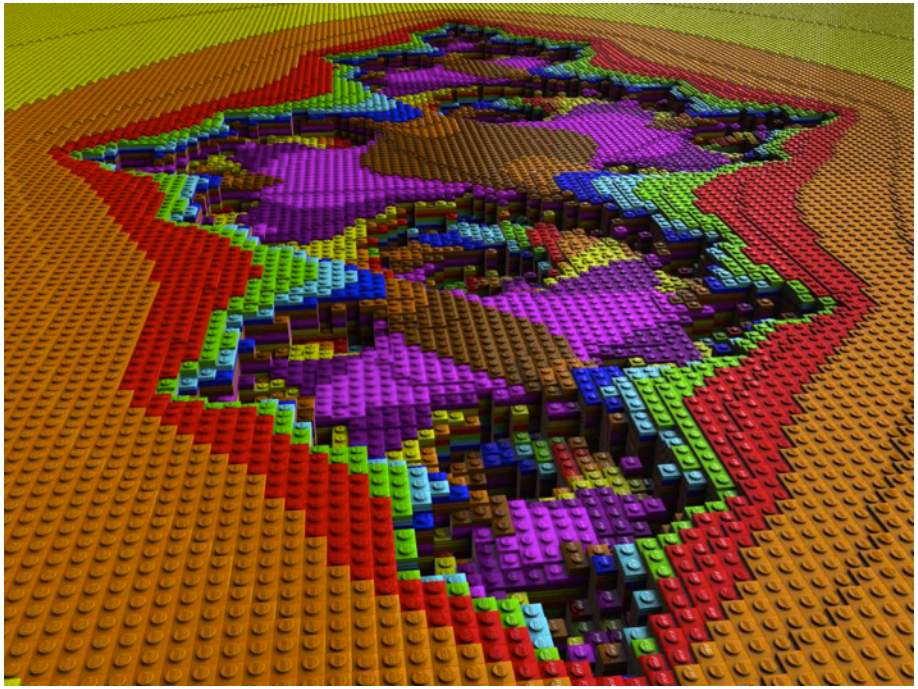
Adv. Mater. **2015**, 27, 2305.

fluorografen

je vhodný materiál pro syntézu (i průmyslovou) širokého spektra grafenových derivátů s obrovským aplikačním potenciálem

… a co dál?





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