TÉCNICO LISBOA

Nanostructured Materials and Nanotechnology 2022-2023

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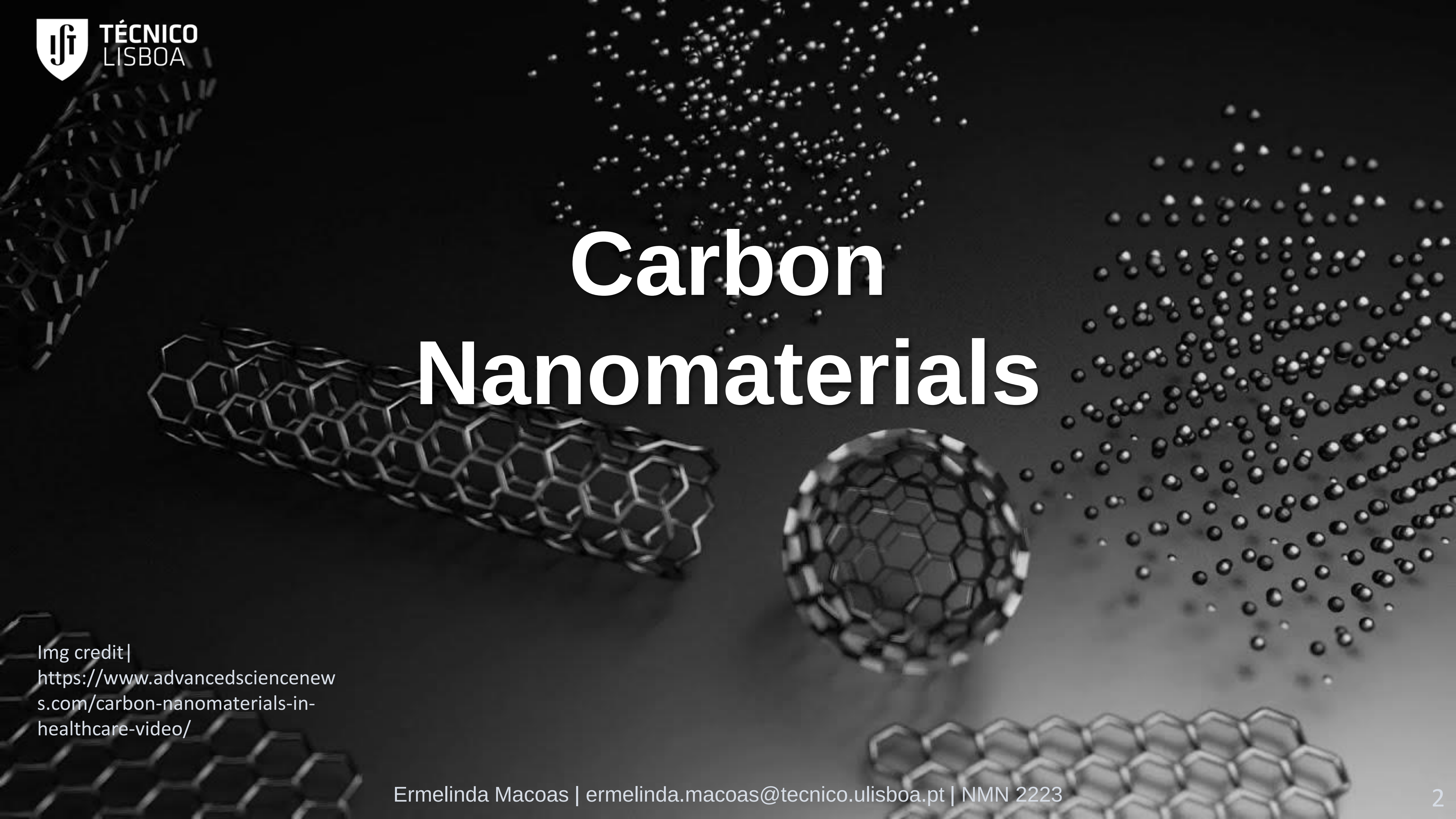

Carbon Nanomaterials

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Content

1. Brief introduction to carbon nanomaterials
2. What is so special about carbon? Carbon hybridization
3. Fullerenes, 1st 0D carbon nanomaterial
4. Carbon nanotubes
5. Graphene

Bibliography

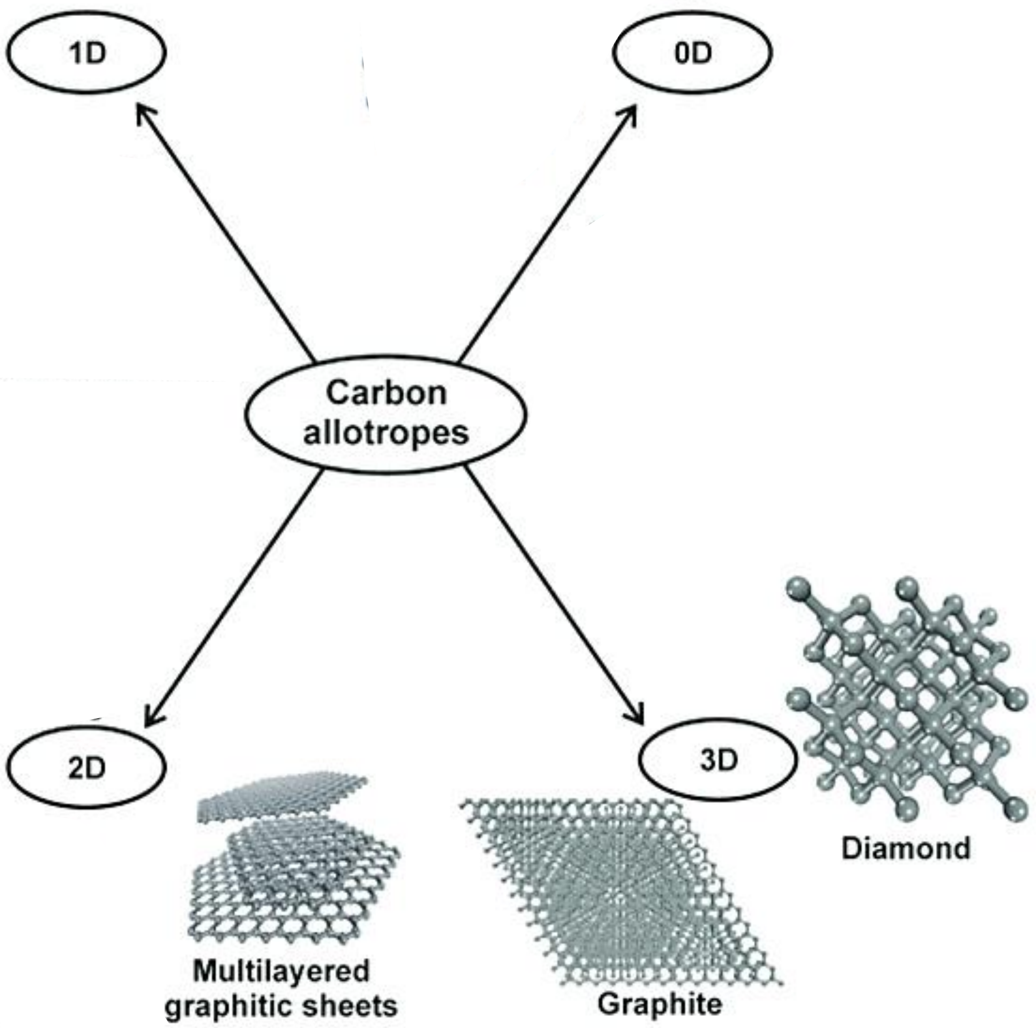
1. “Science and Technology of the Twenty-First Century: Synthesis, Properties, and Applications of Carbon Nanotubes” Mauricio Terrones, Annu. Rev. Mater.Res. 2003. 33:419–501 doi: 10.1146/annurev.matsci.33.012802.100255

2. “Carbon Nanotubes: Present and Future Commercial Applications” Volder et al, Science, 2013, 339, 535, http://science.sciencemag.org/content/339/6119/535

3. “Review of the synthesis, transfer, characterization and growth mechanisms of single and multilayer graphene” Lee et al, RSC Adv., 2017, 7, 15644 https://doi.org/10.1039/C7RA00392G

4. “Advances and Trends in Chemically Doped Graphene”, Rümmeli et al, Adv. Mater. Interfaces 2020, 7, 2000999, http://doi.org/10.1002/admi.202000999

Carbon Nanomaterials



Carbon materials

Short Chronology

1779 – Graphite (Scheele in 1779, John D. Bernal 20th)

1814 – Diamond (Davy)

1985 – Fullerenes (Kroto, Smalley, Curl)

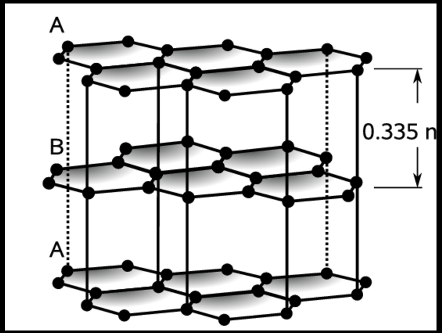
Nobel Prize in Chemistry 1996

1991 – Carbon nanotubes (Iijima)

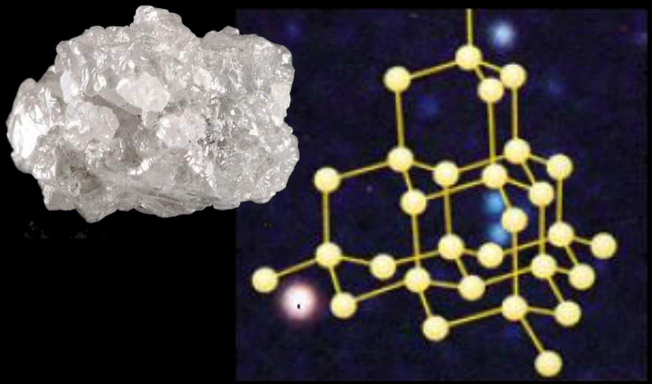
1997 – Carbon nanofoam (Giapintzakis)

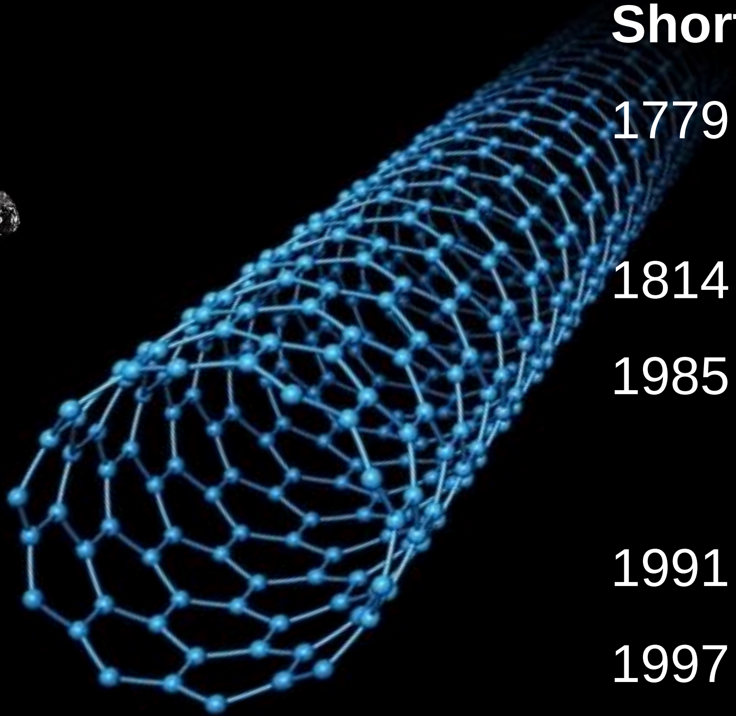
2004 – Graphene (Geim and Novoselov),

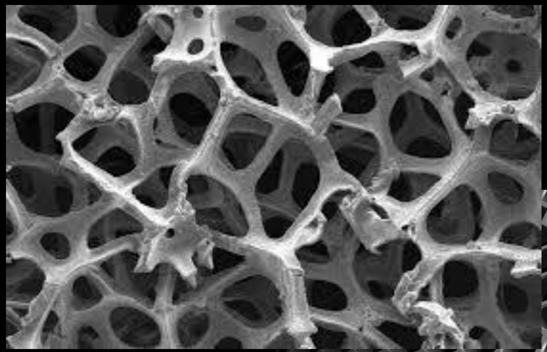
Nobel Prize in Physics 2010

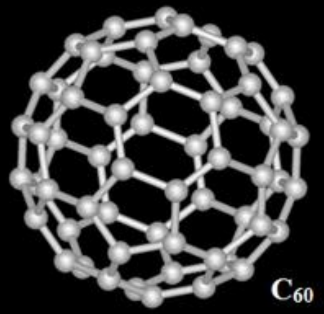


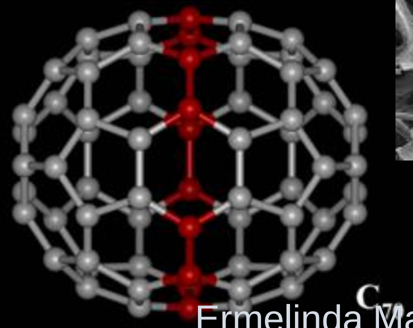
Diamond











Graphene

Dresselhaus & Terrones
Proceedings of the IEEE, 2013, 101 (7)
doi: 10.1109/JPROC.2013.2261271

Mildred S. Dresselhaus
Queen of Carbon Science

https://youtu.be/xHeO9EYJHIs

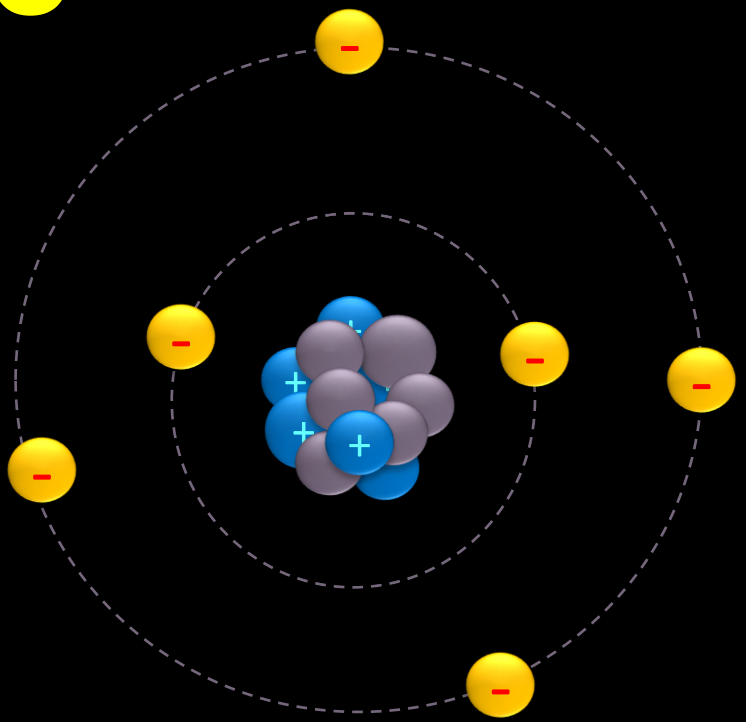
^{6}C

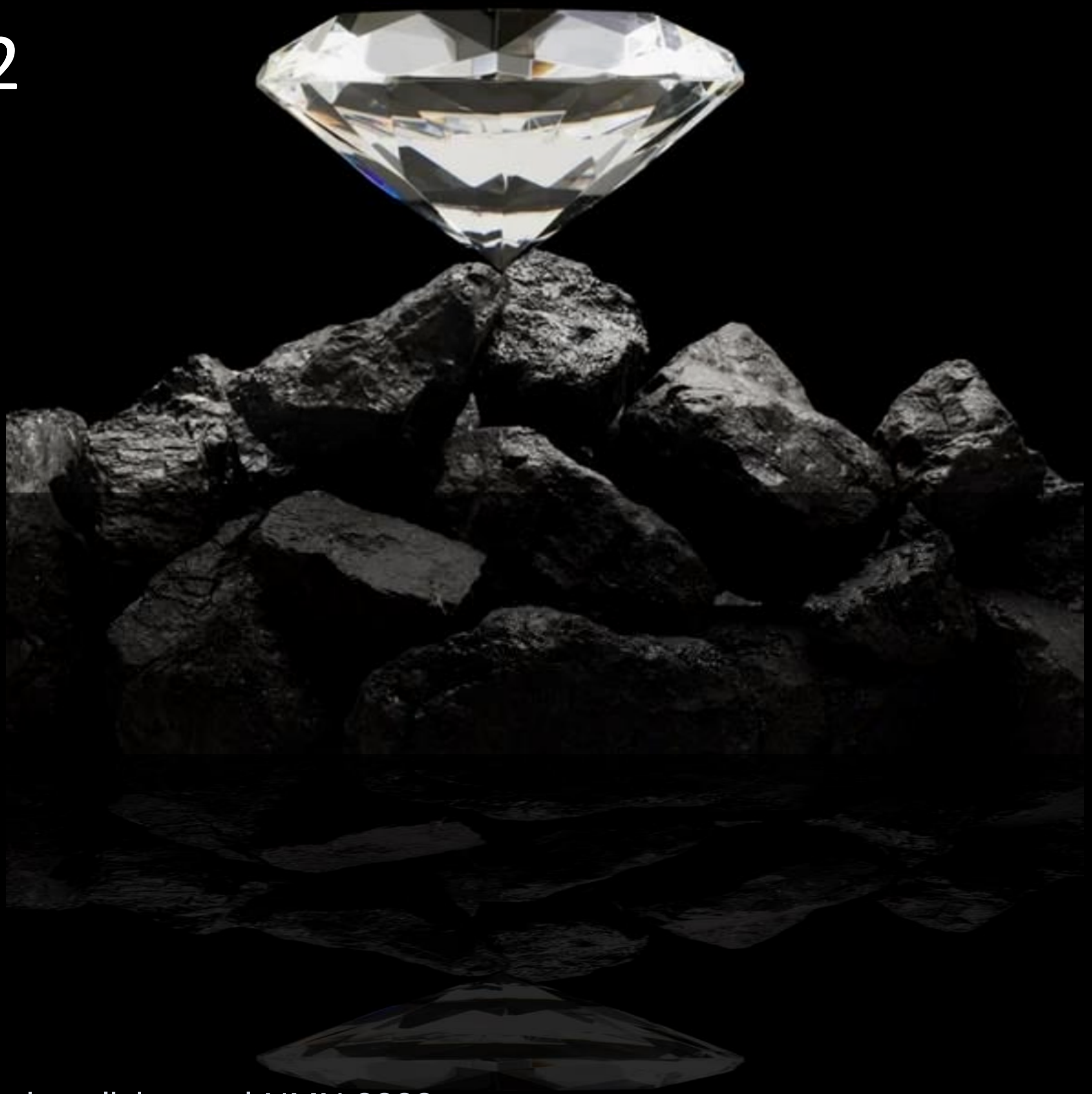
Carbono

$1s^2$

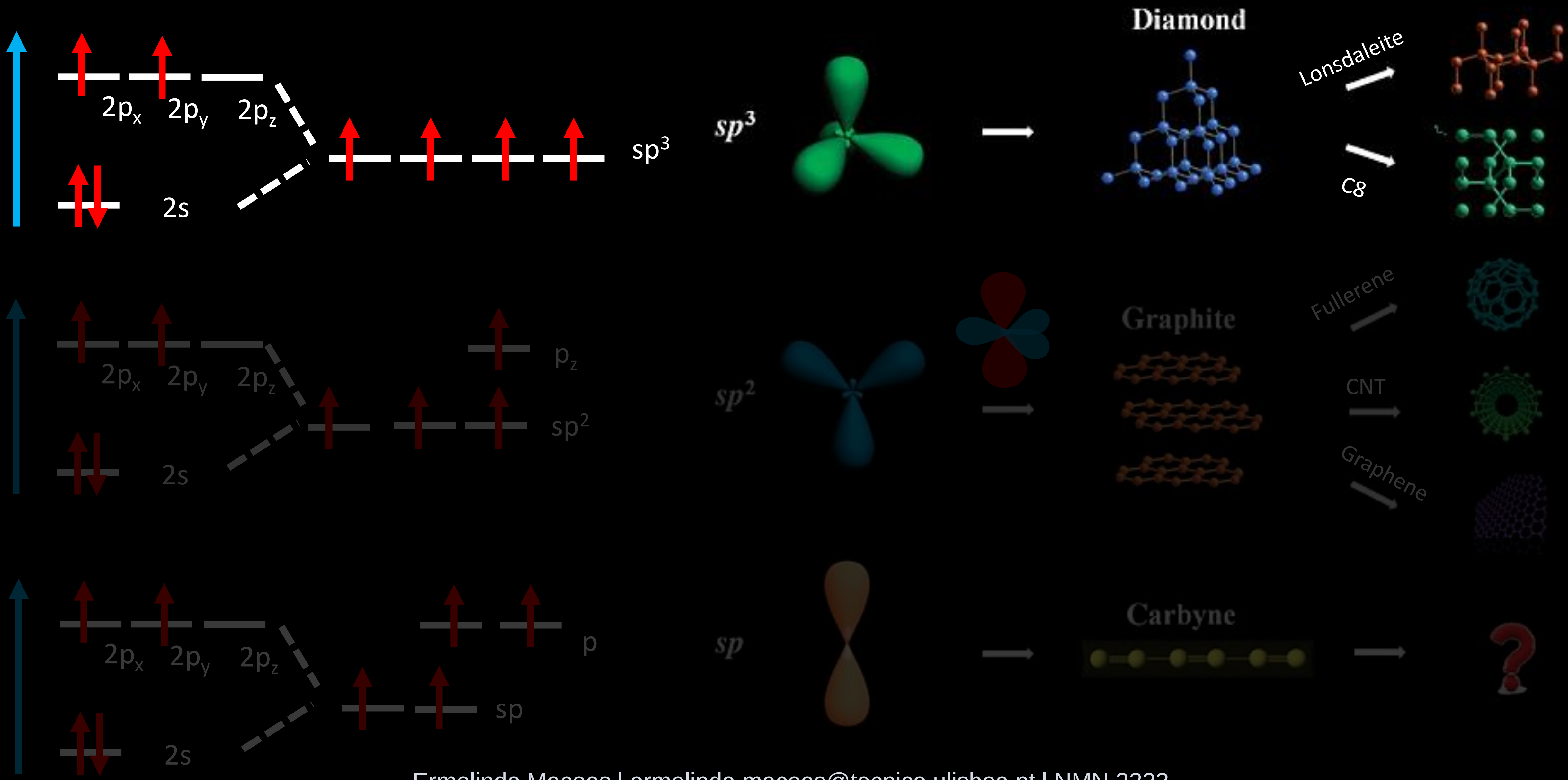
$2s^2\ 2p^2$

6

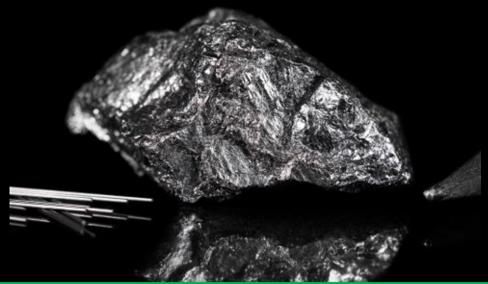


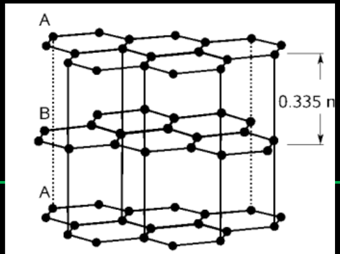


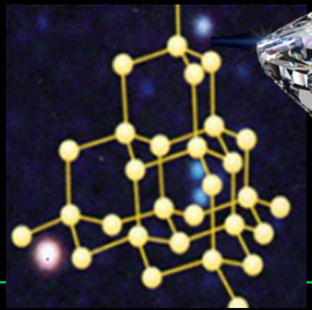
Carbon hybridization

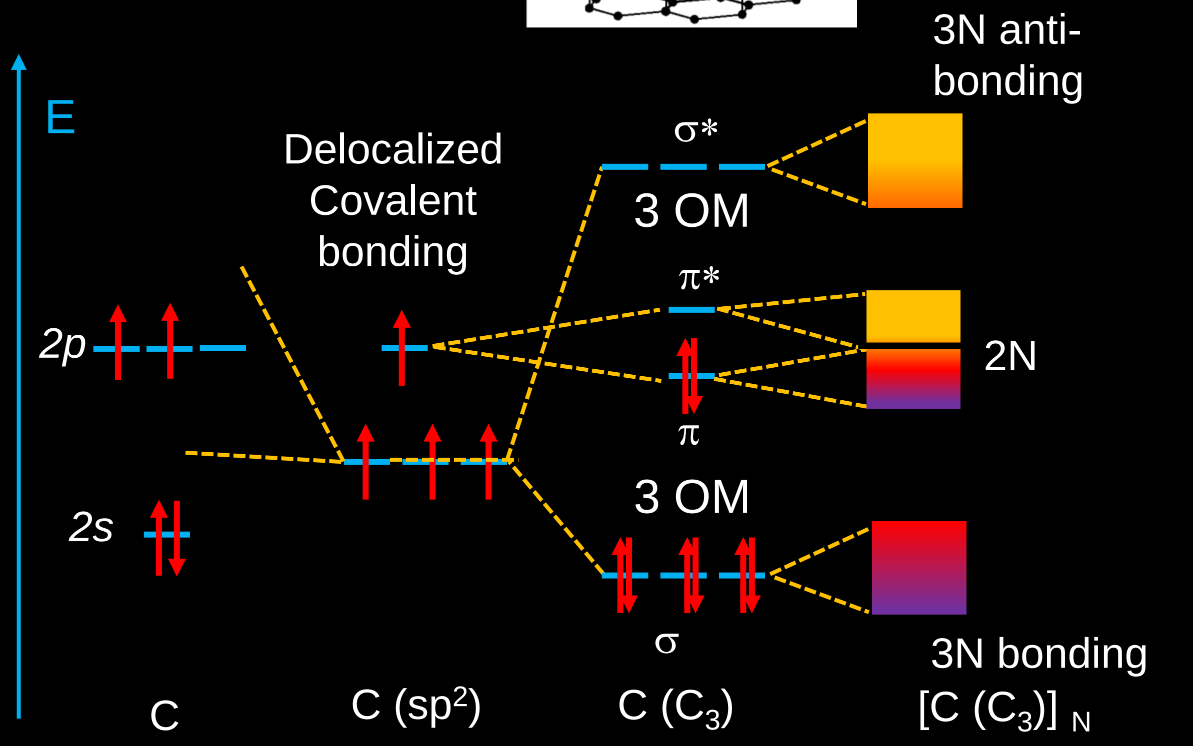


Diamond vs graphite
sp^3 vs sp^2

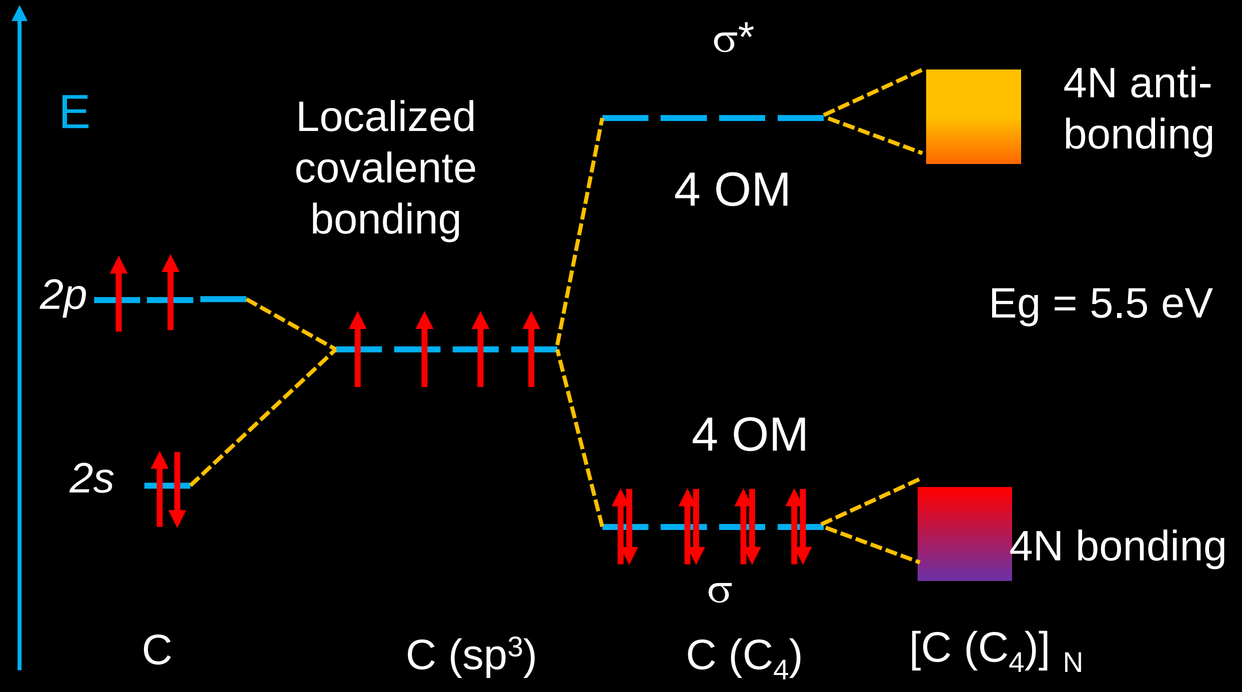








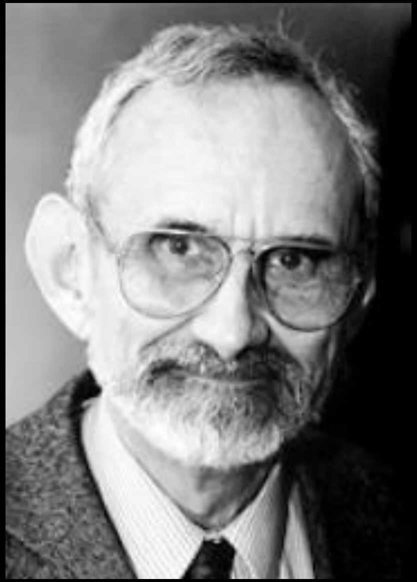
Condutor σ ≈ 10^2 - 10^5 S/m

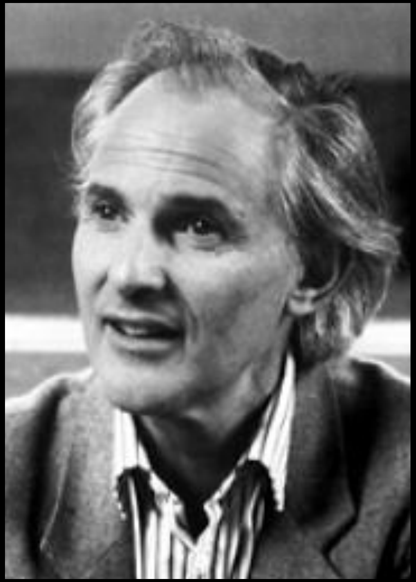


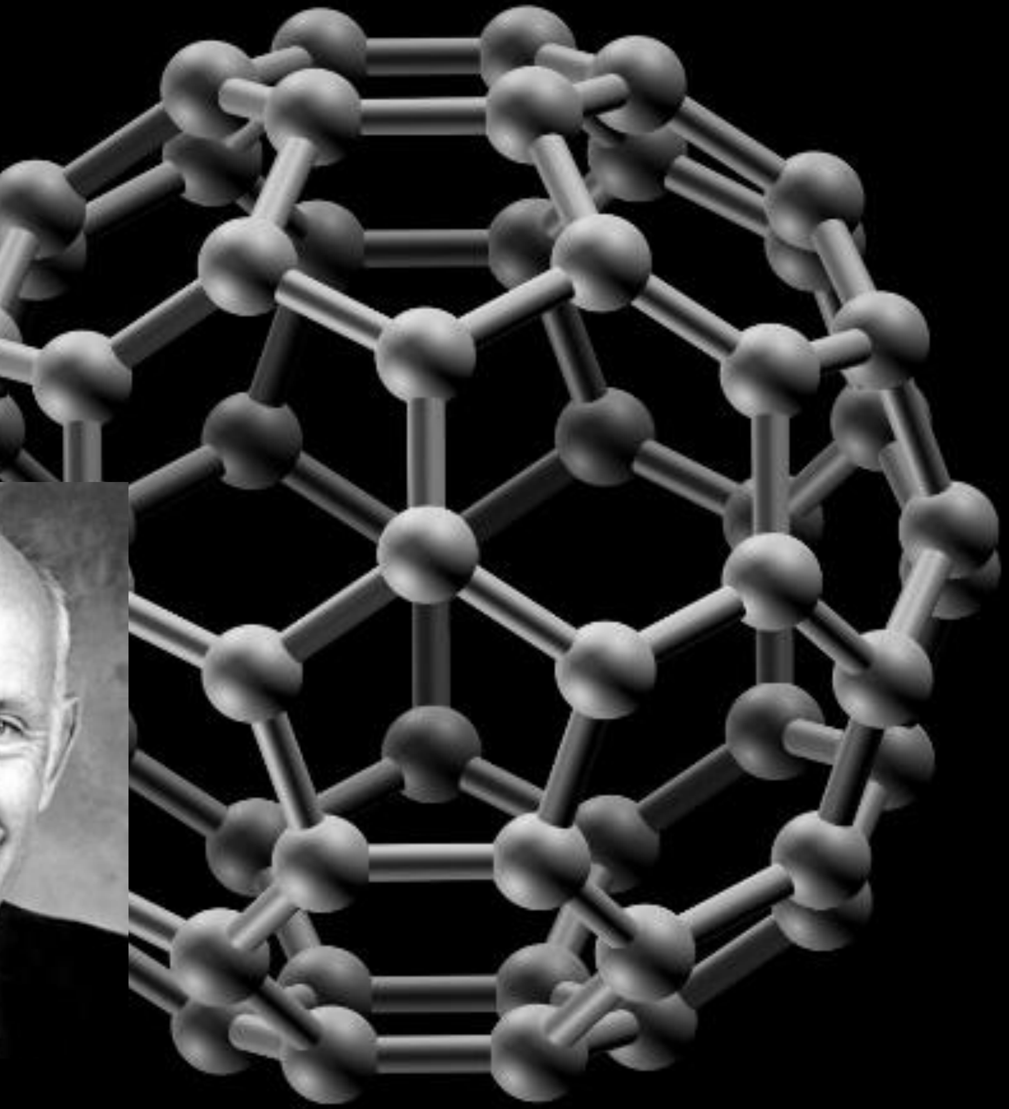
Insulator σ ≈ 10^{-13} S/m

Nobel Prize in Chemistry 1996

Fullerenes





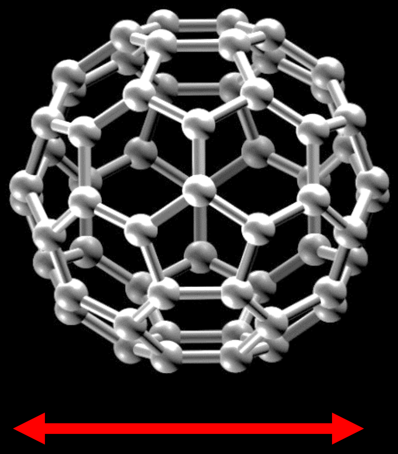


Robert F.Curl Jr.
Rice University

Sir Harold W. Kroto
Sussex University

Richard E. Smalley
Rice University

Fullerenes



even numbers of carbons

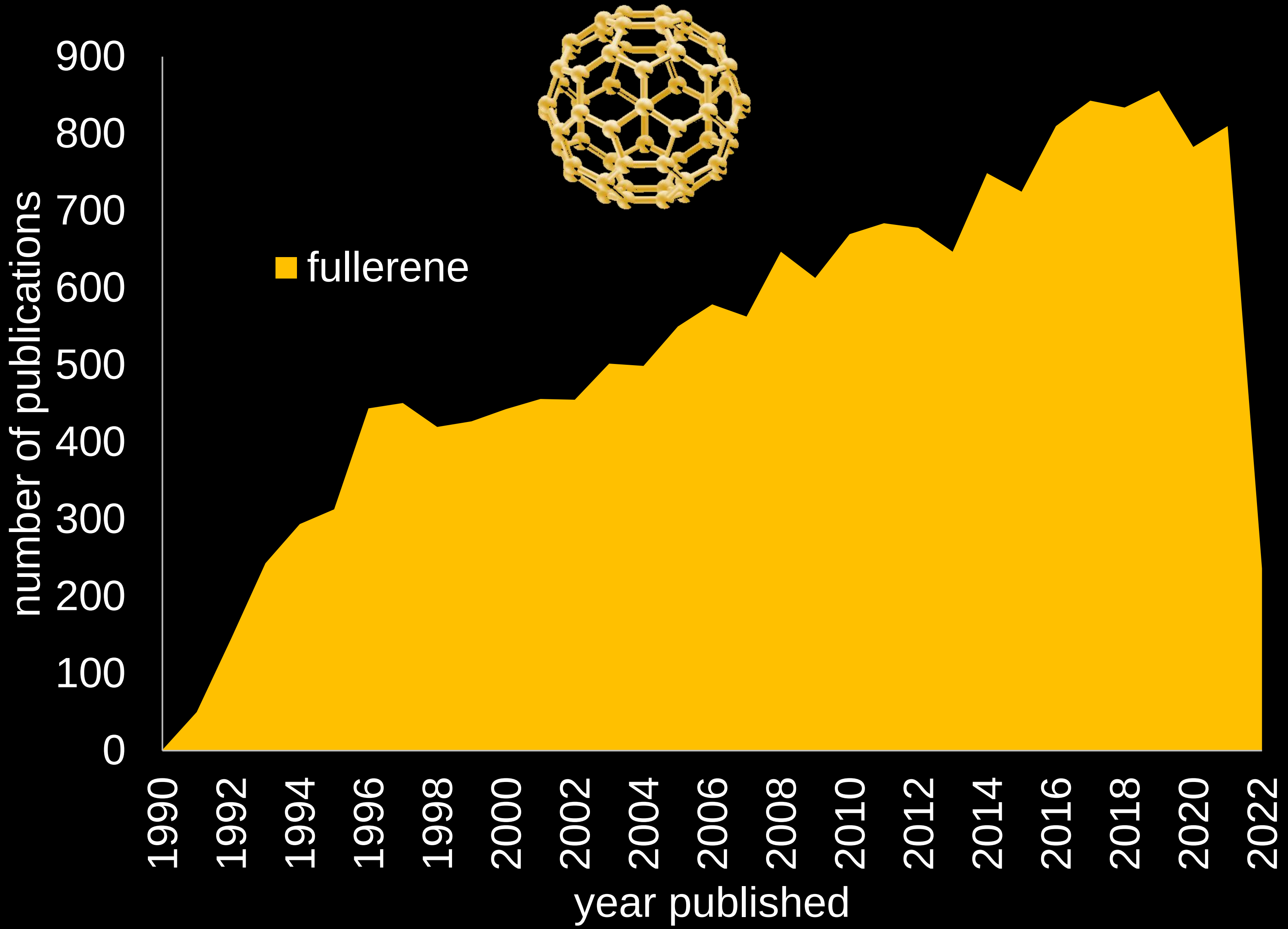
$C_{20+2x\text{Hex faces}}$

12 pentagonal rings
m = (Cn-20)/2 hex rings

- High molecular symmetry
- Large number of delocalized p-electrons
- Strong electron acceptors (radical scavengers/antioxidant)
- High triplet generation yield (singlet oxygen sensitizer = oxidant)
- Good thermal and pressure stability

Color	Black Solid
Odor	Odorless
Formula	C_{60}
Weight	720.65
Density	1.7 to 1.9 gcm^{-3}
Standard heat of formation	9.08 k $calmol^{-1}$
Index of refraction	2.2 (600nm)
Boiling point	Sublimes at 800K
Resistivity	1014 ohms m^{-1}
Crystal form	Hexagonal cubic
Optical band gap	1.68 eV
Vapor pressure	5×10^{-6} torr at room temperature and 8×10^{-4} torr at 800K
Solubility	Benzene, toluene and chloroform

Poor solubility (1-5 mg/ml) strongly limits processability


fullerene
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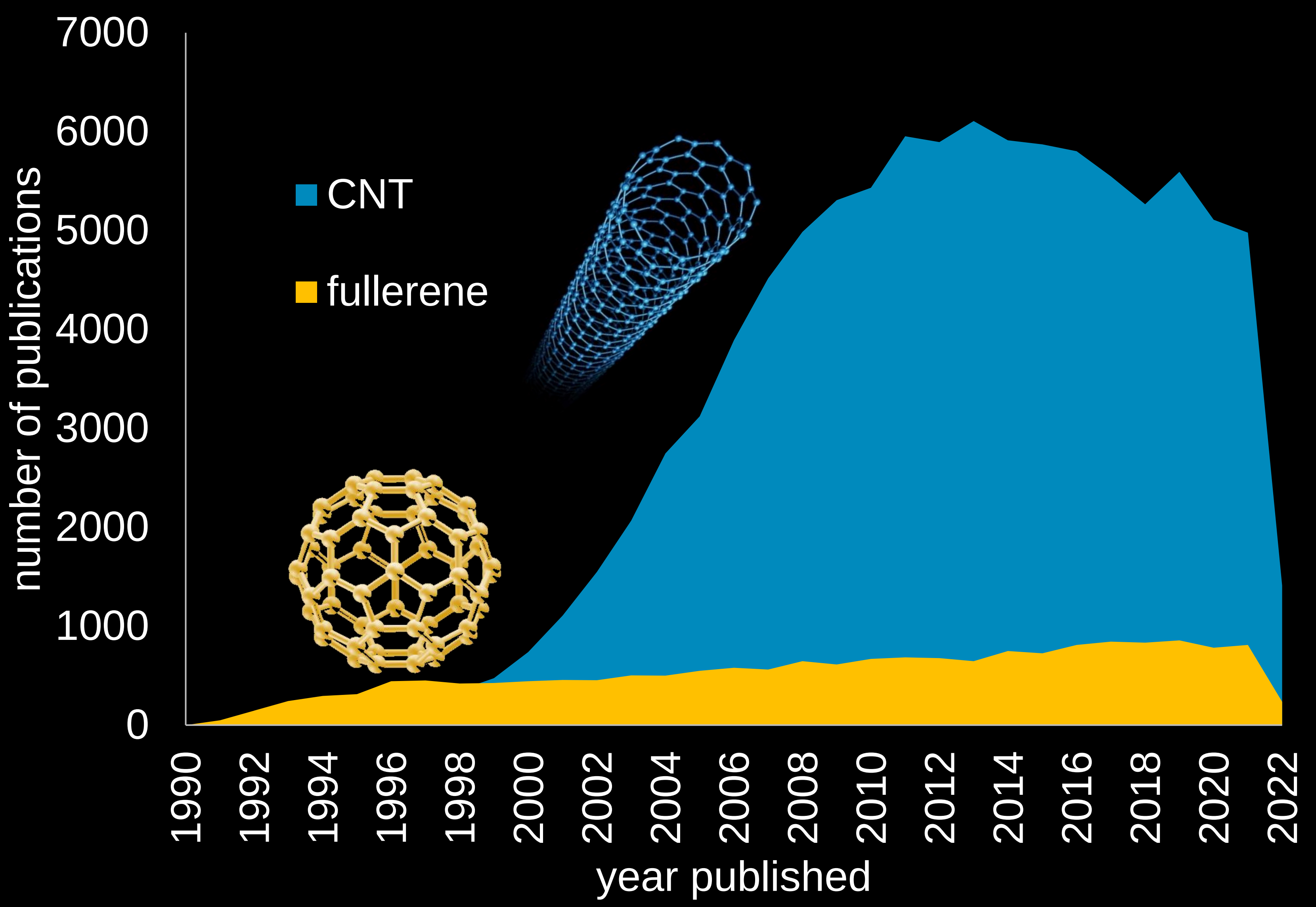
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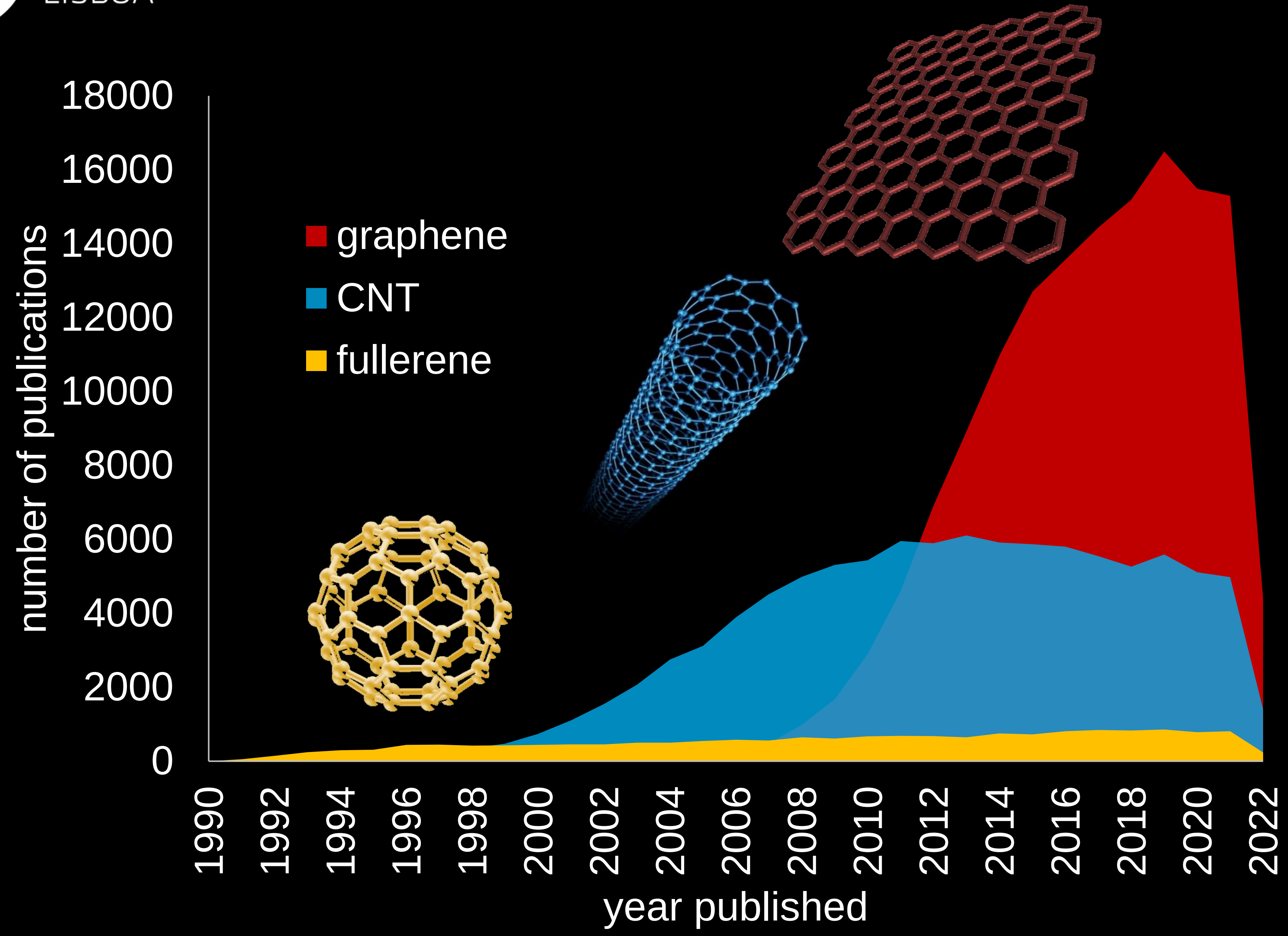
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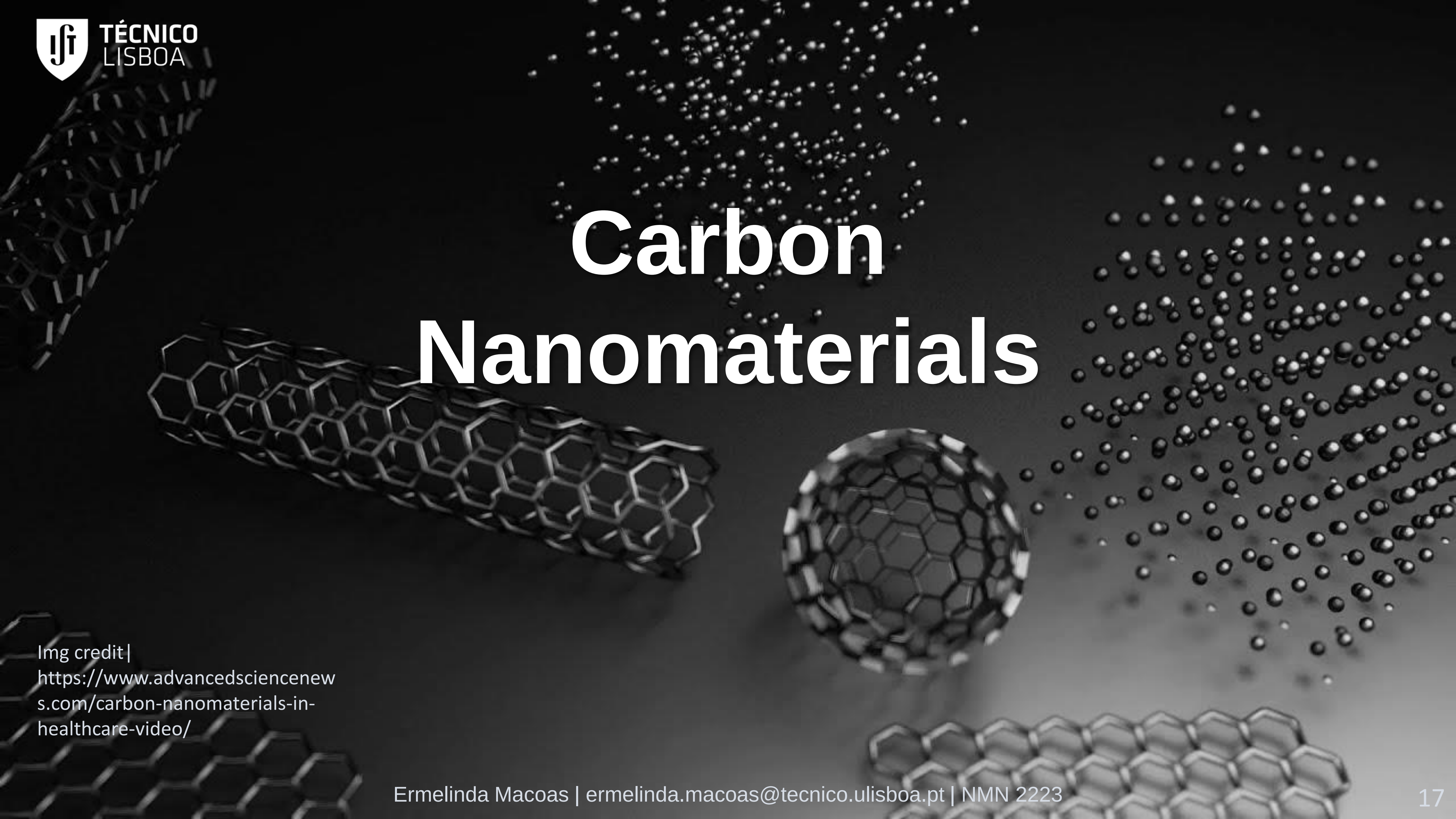

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