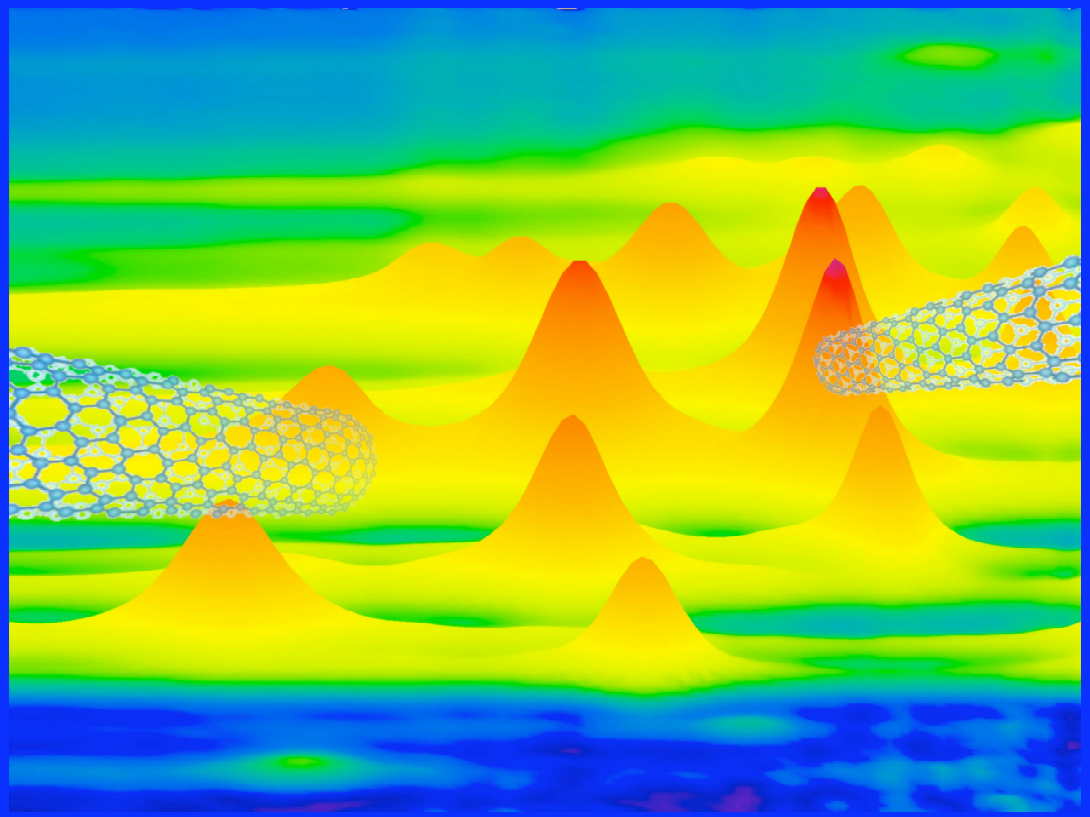
NANOTECH, NANOTUBES and ENERGY



DOE NSRC Workshop
February 27, 2003

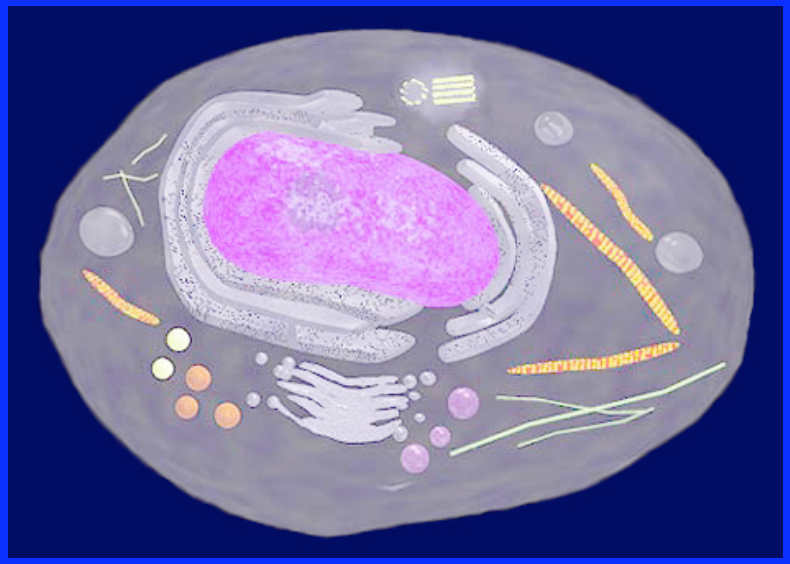
R. E. Smalley
Rice University

Nanotechnology

- The art and science of building stuff that does stuff at the nanometer scale
- The ultimate nanotechnology builds at the ultimate level of finesse one atom at a time, and does it with molecular perfection
- It holds the answer, to the extent there are answers, to most of our most pressing material needs.

The Wet Side of Nanotechnology

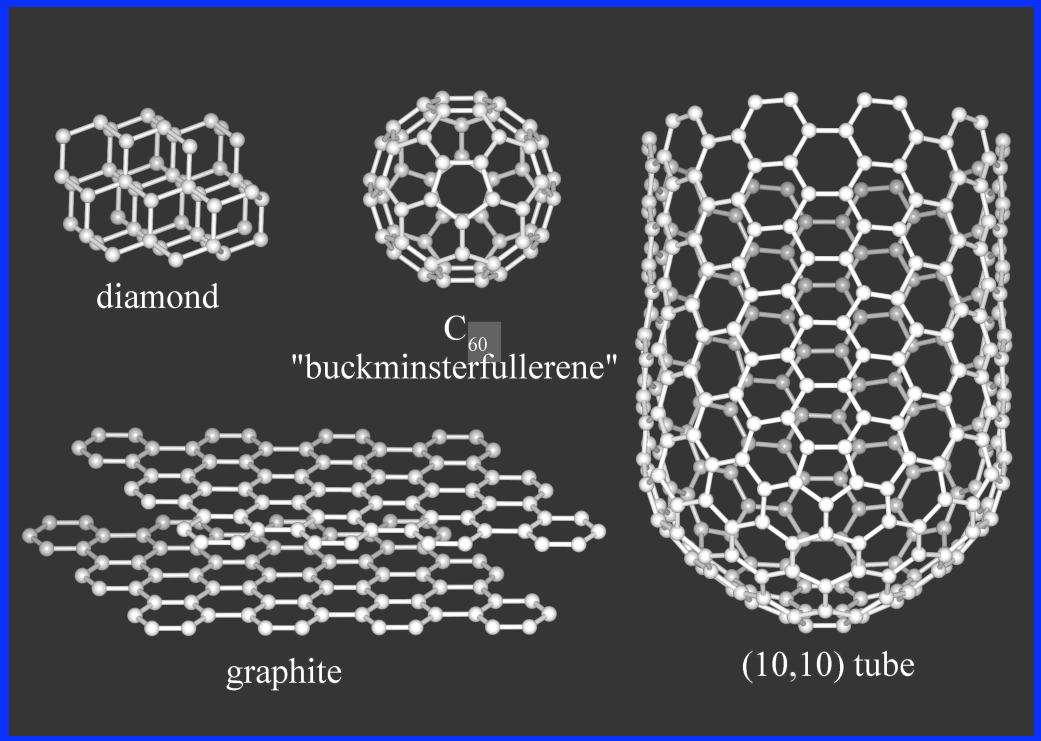
- All the nano-machinery of cellular life (and viruses)



- Biotechnology is a form of Nanotechnology (the wet side)

The Dry Side of Nanotechnology

- Electrical & thermal conduction
- Great strength, toughness, high temperature resistance, etc

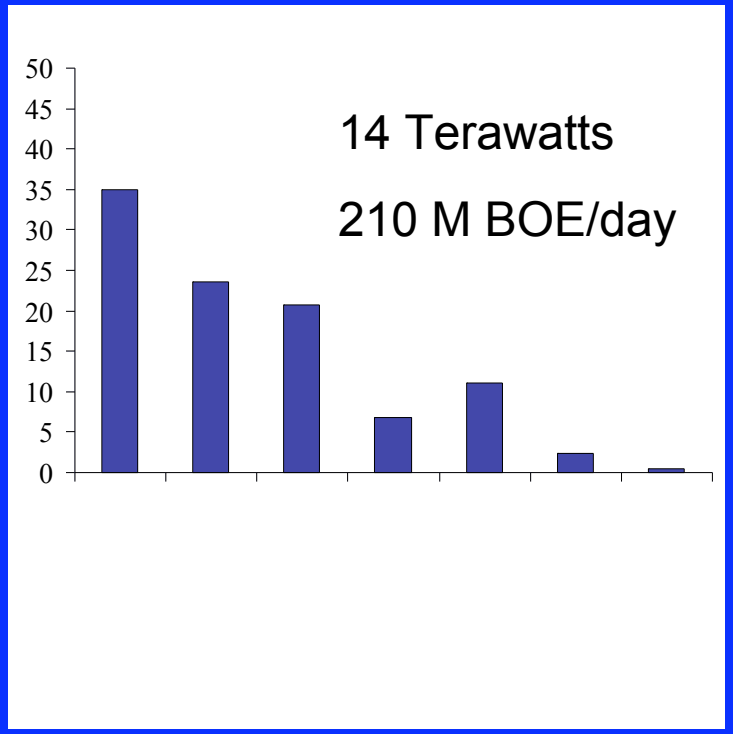


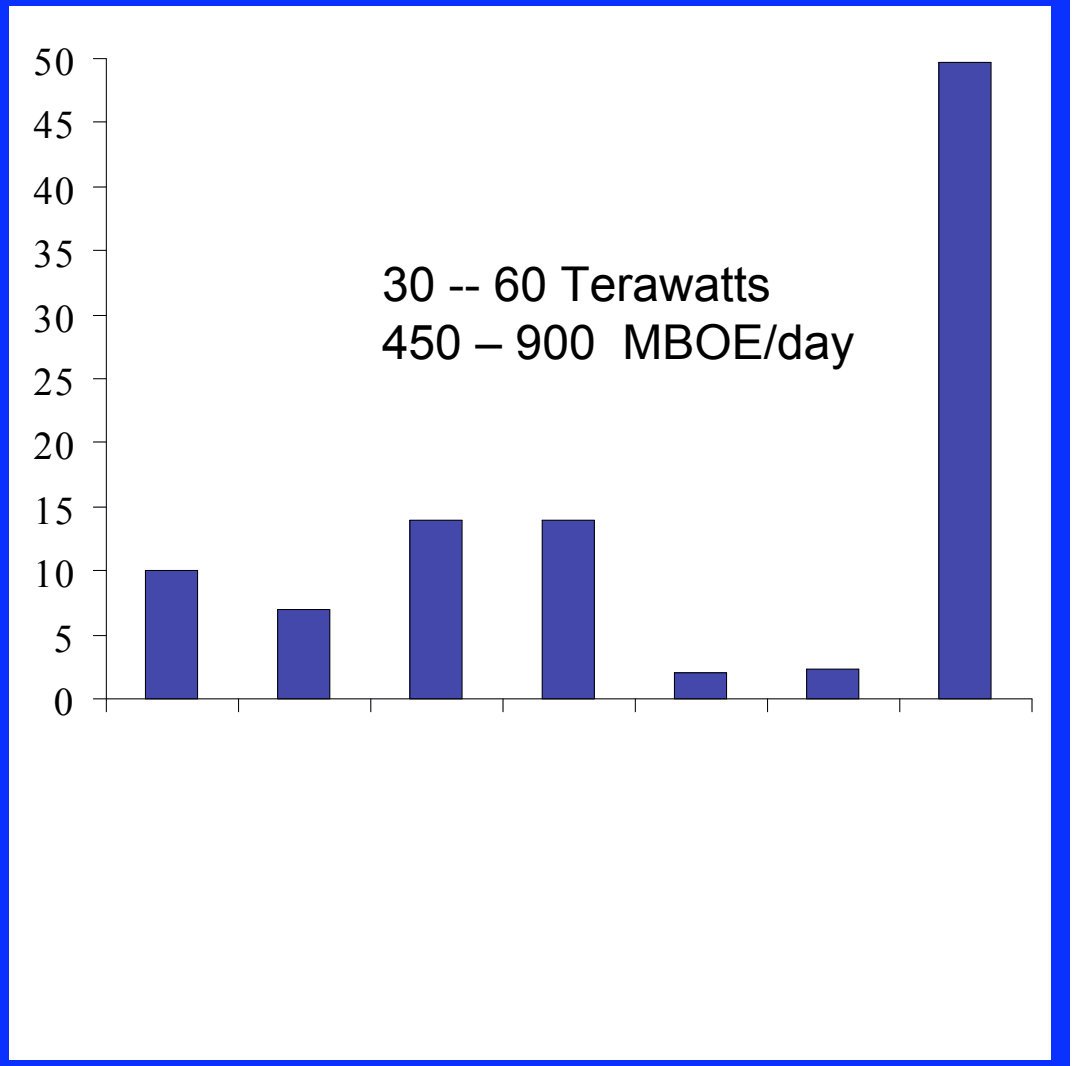
Humanity's Top Ten Problems for next 50 years

1. ENERGY
2. WATER
3. FOOD
4. ENVIRONMENT
5. POVERTY
6. TERRORISM & WAR
7. DISEASE
8. EDUCATION
9. DEMOCRACY
10. POPULATION

2003	**6.3**	**Billion People**
2050	**9-10**	**Billion People**

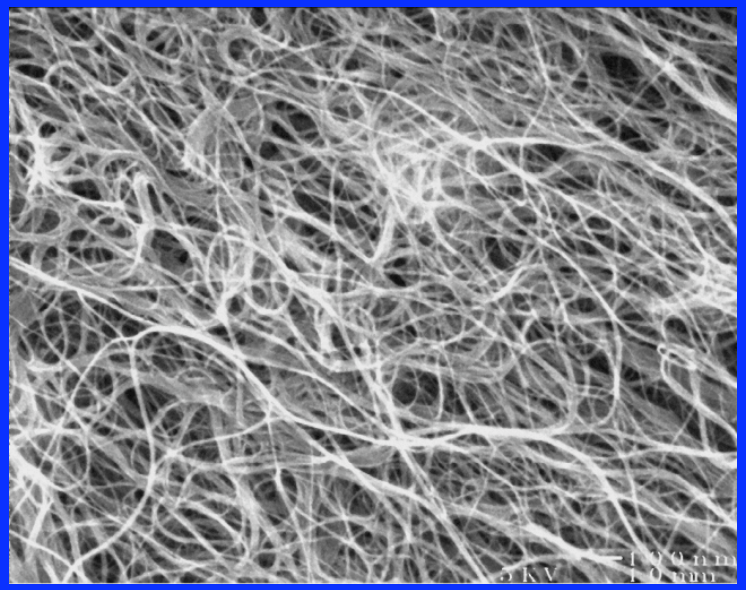
The ENERGY REVOLUTION (The Terawatt Challenge)

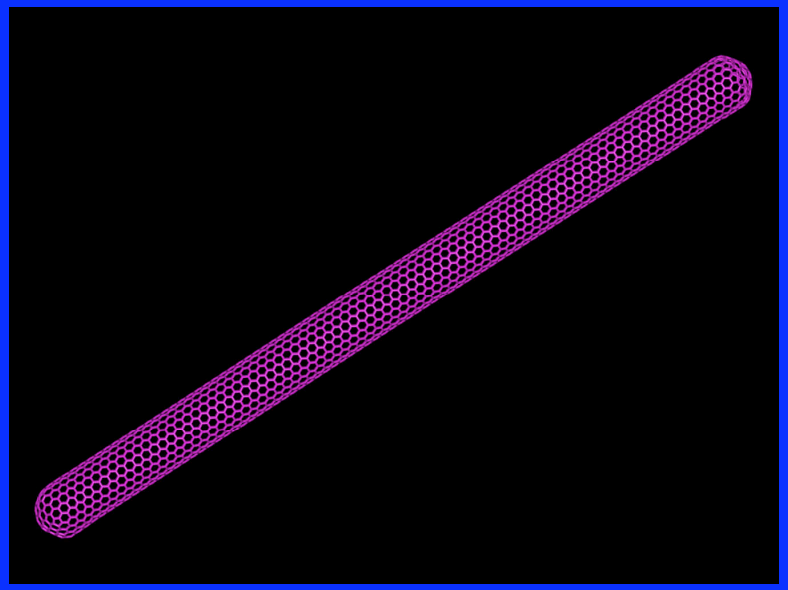


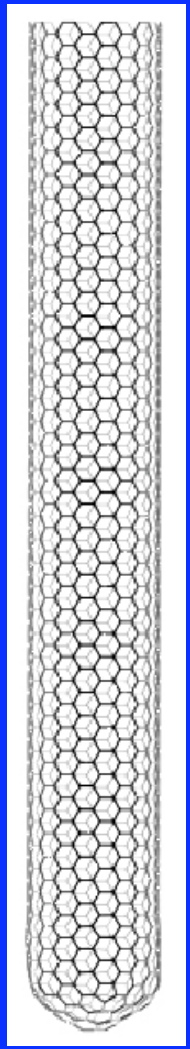


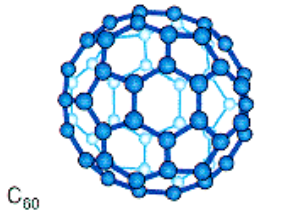
MOLECULAR PERFECTION: The FULLERENE IDEAL

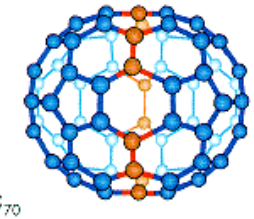
- The Strongest fiber that will ever be made.
- Electrical Conductivity of Copper or Silicon.
- Thermal Conductivity of Diamond.
- The Chemistry of Carbon.
- The size and perfection of DNA.

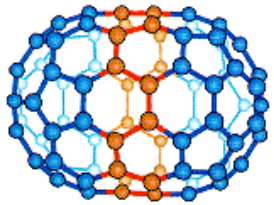




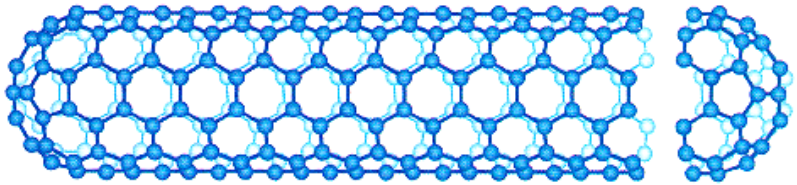






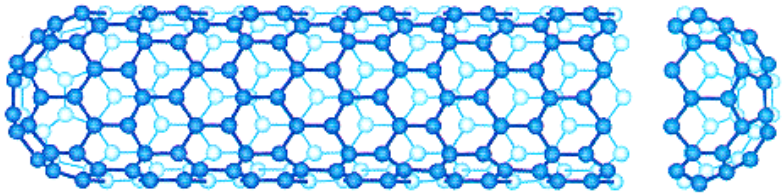


a



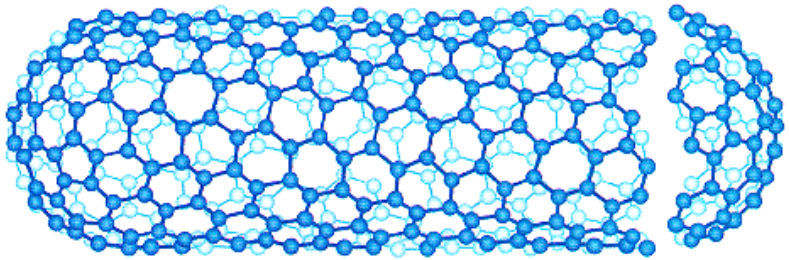
(n,m) = (5,5)

b



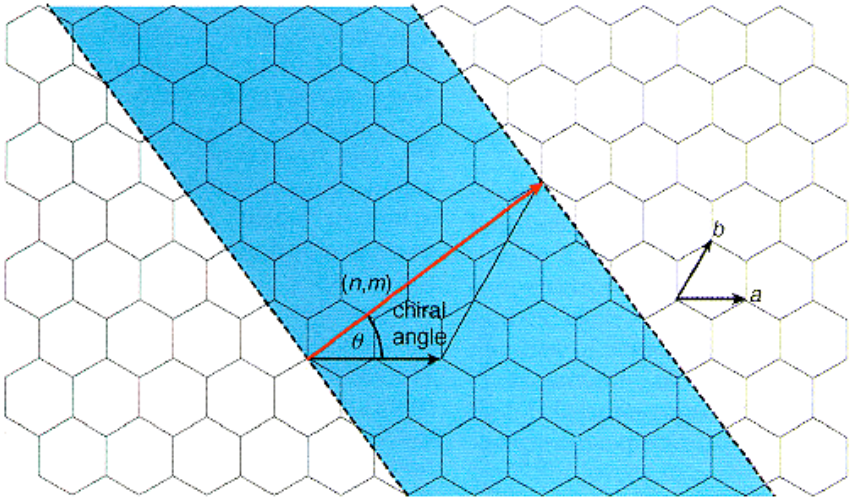
(n,m) = (9,0)

c

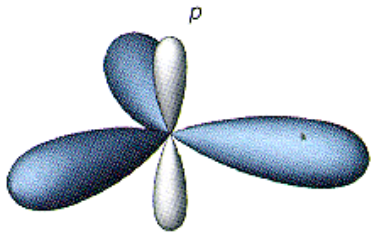


(n,m) = (10,5)

d

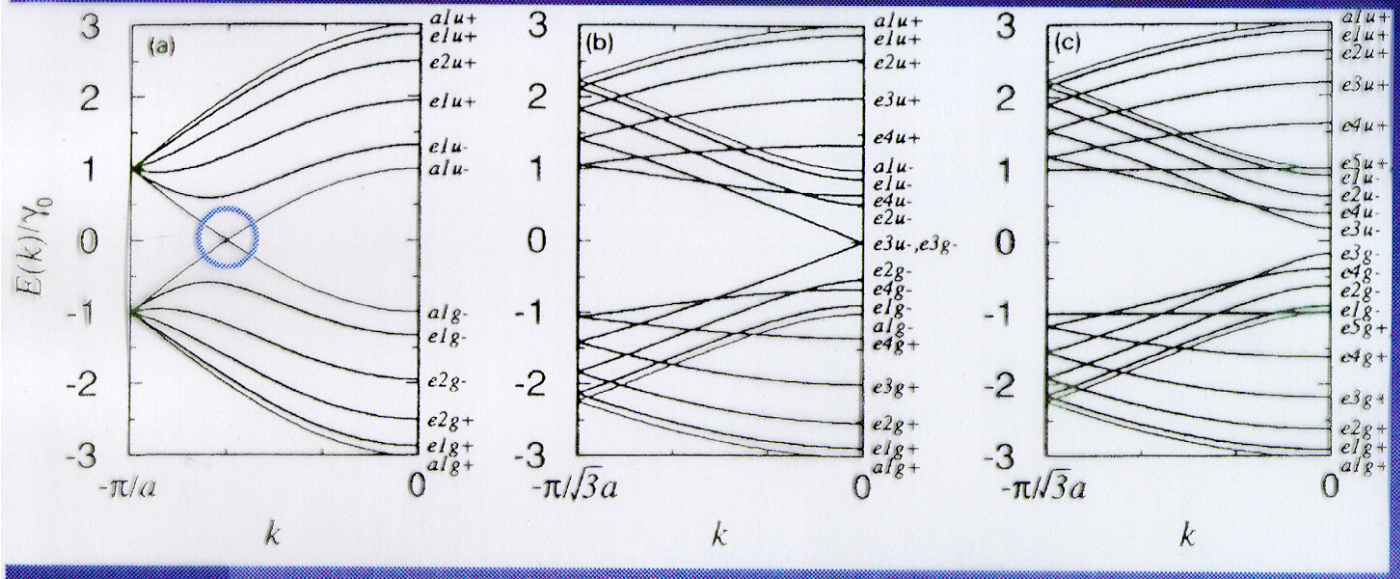


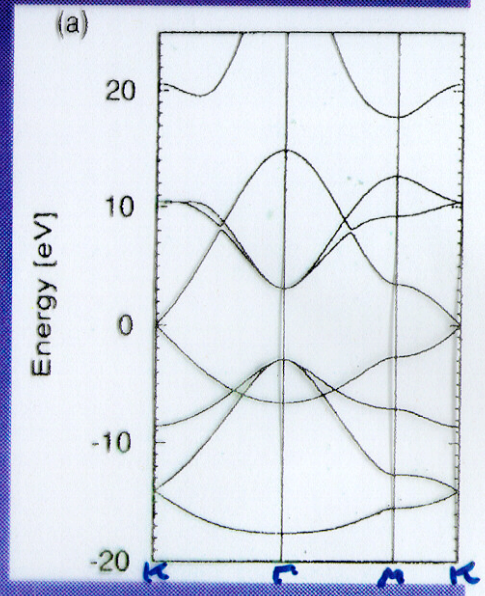
e



f

Band structures for various arrangements of graphene

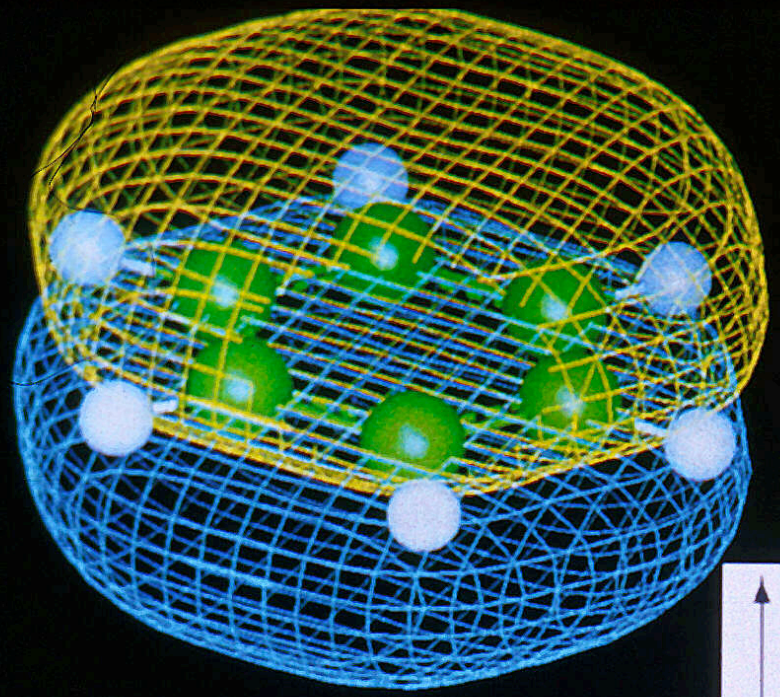


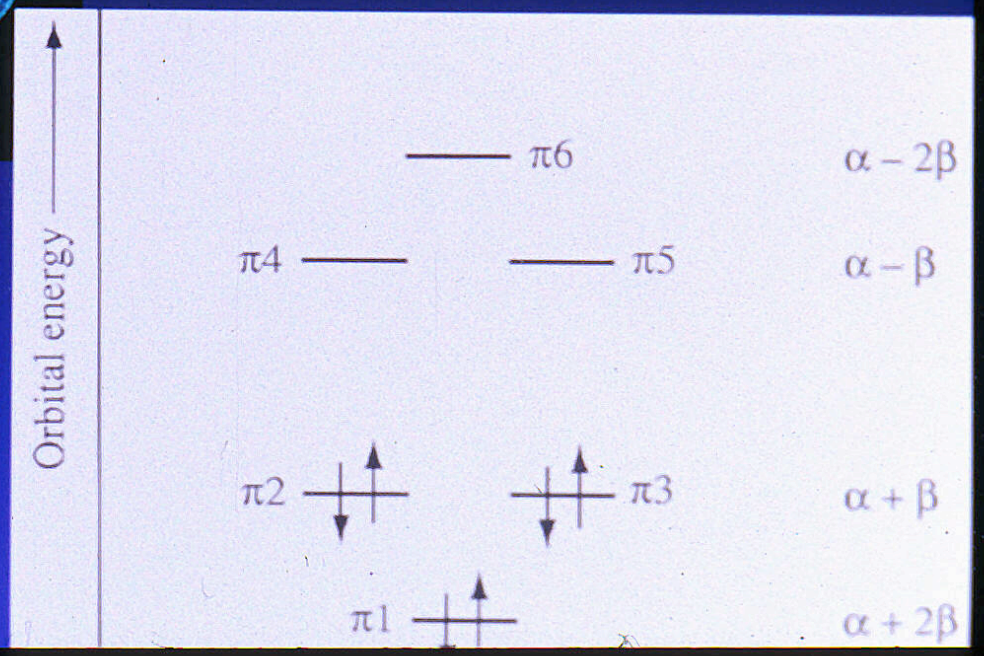


(5,5) tube (armchair) **(9,0) tube (zigzag)** **(10,0) tube (zigzag)** **planar graphene**

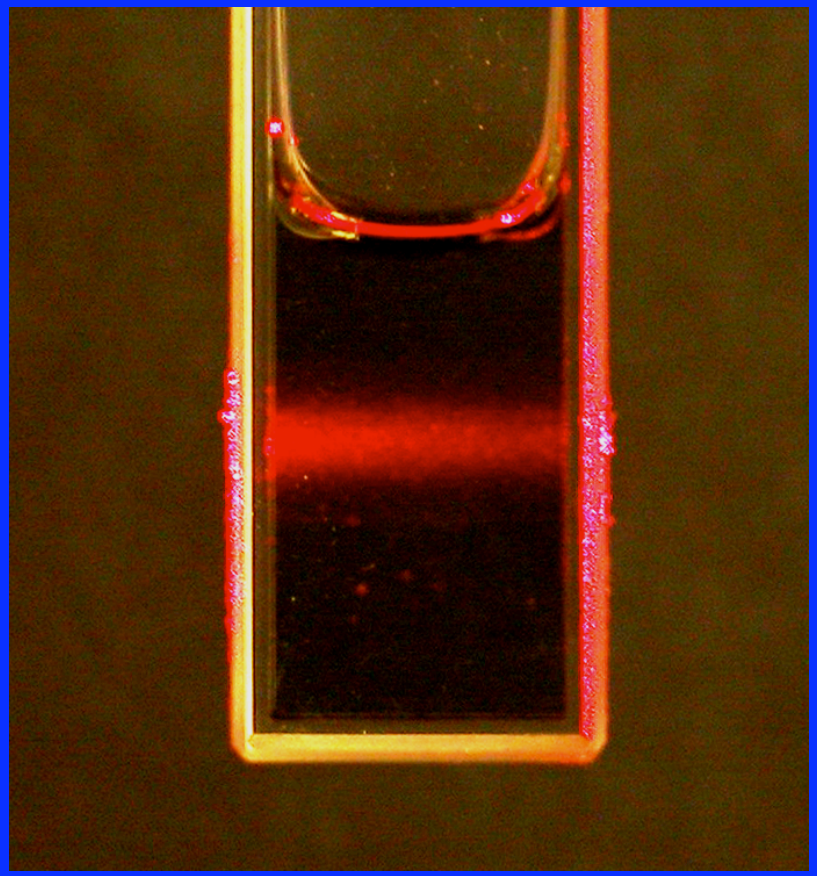
M.S. Dresselhaus, G. Dresselhaus, P.C. Eklund, **Science of Fullerenes and Carbon Nanotubes**, Academic (1996).

BENZENE

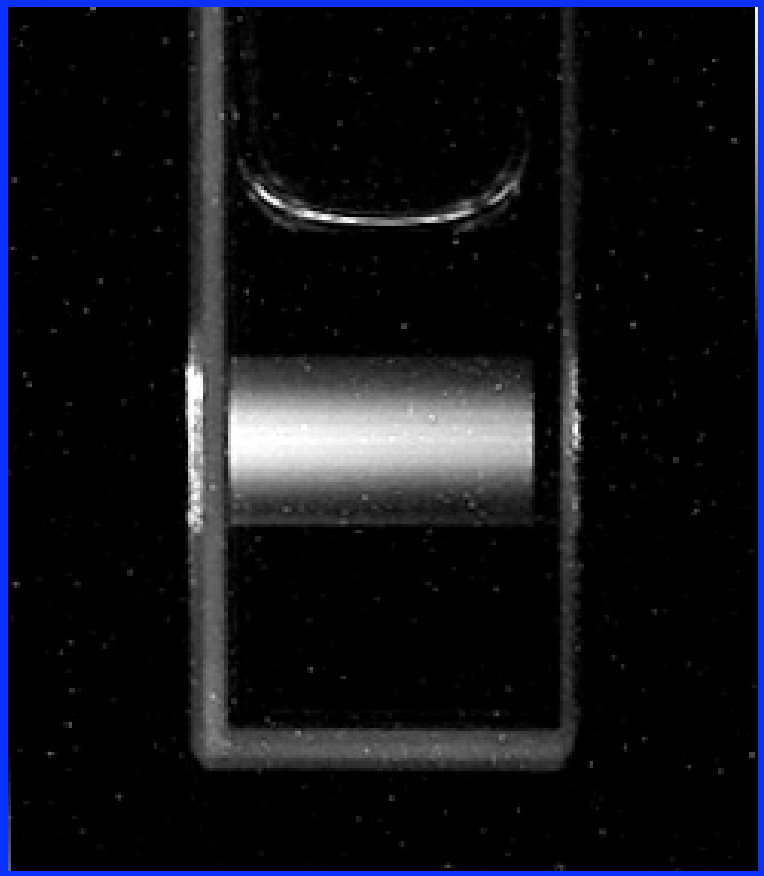




Near-infrared Photoluminescence from Single-wall Carbon Nanotubes

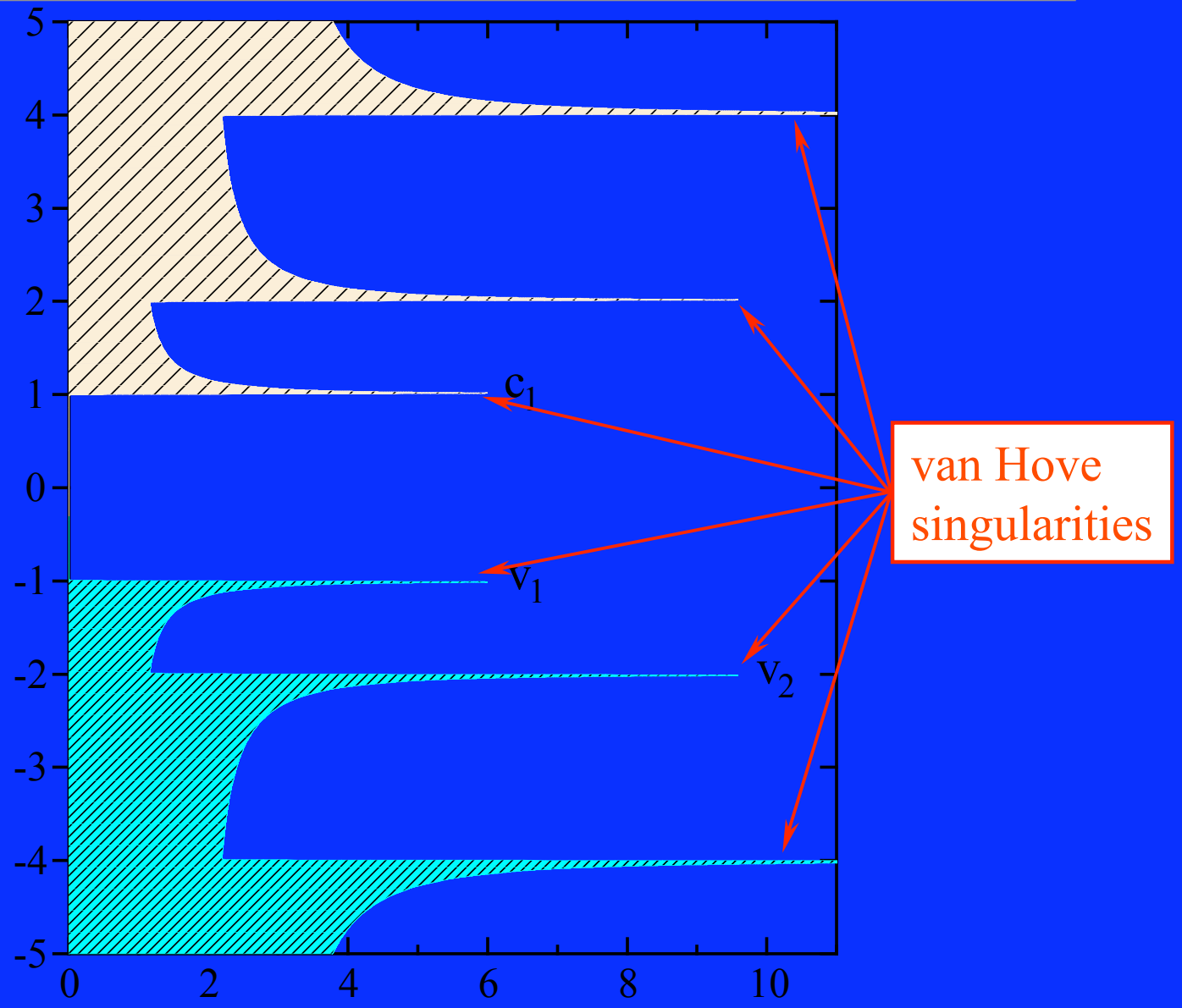


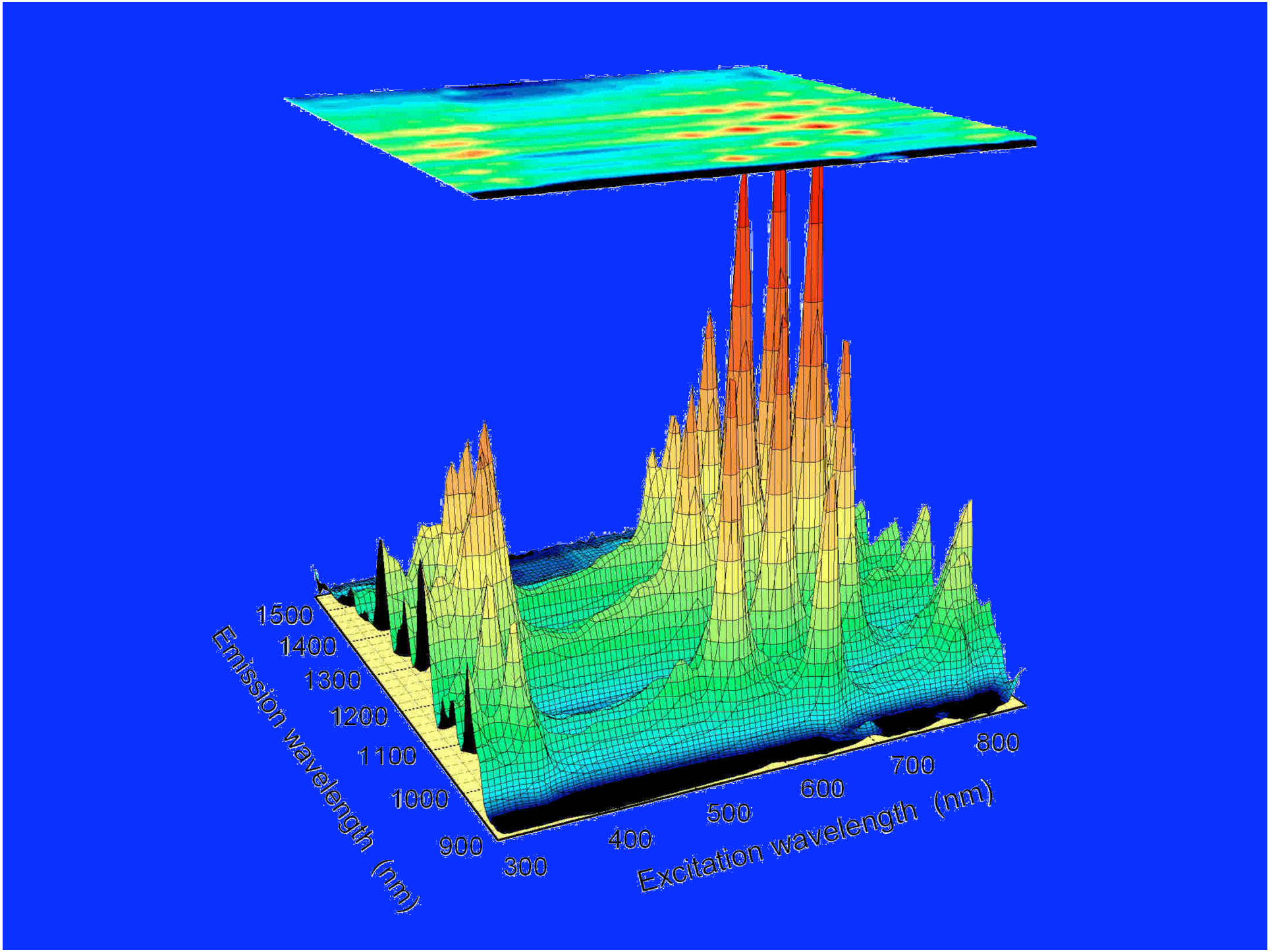
Excitation (661 nm)



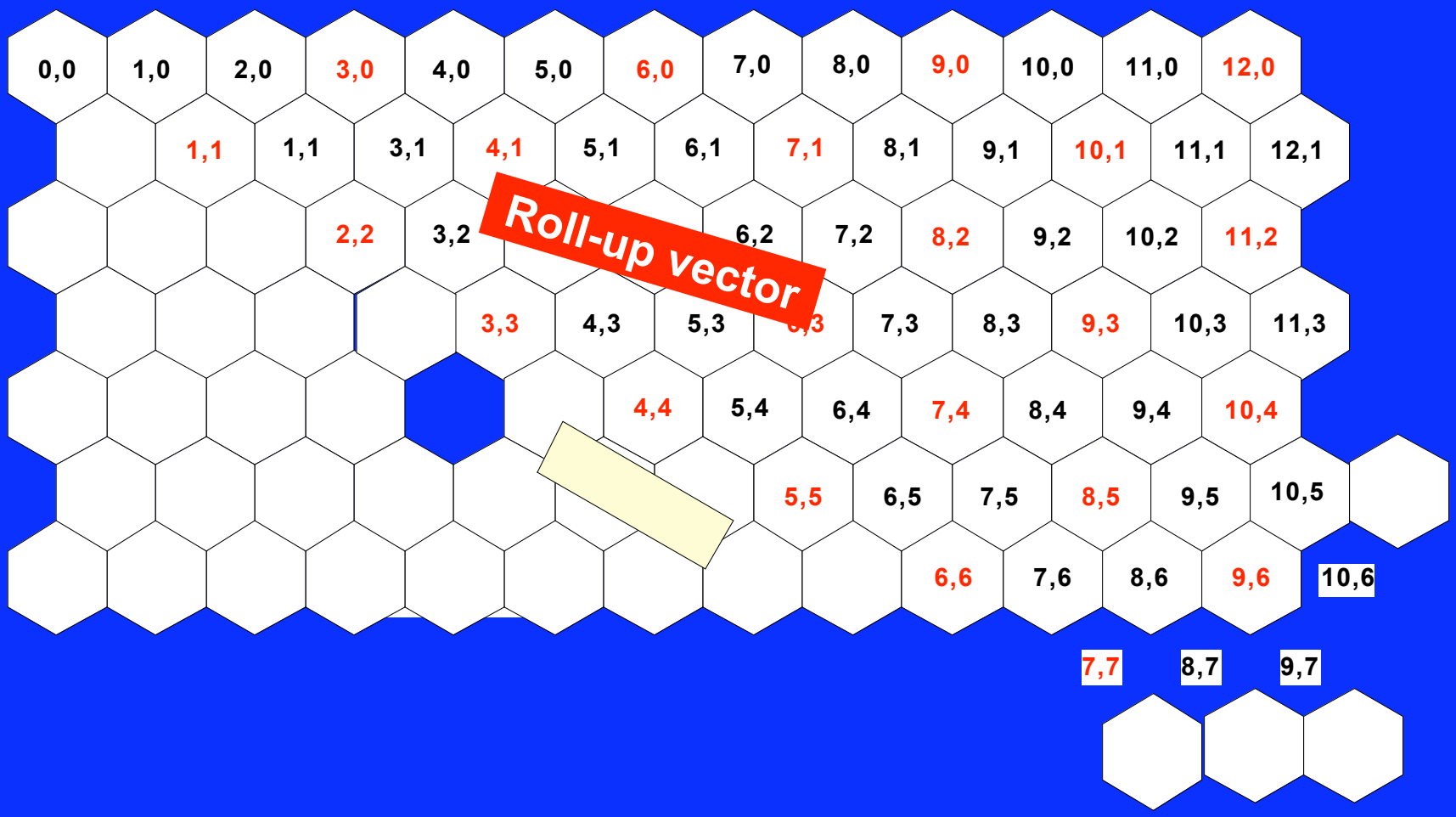
Emission (> 850 nm)

Electronic States of Semiconducting SWNT

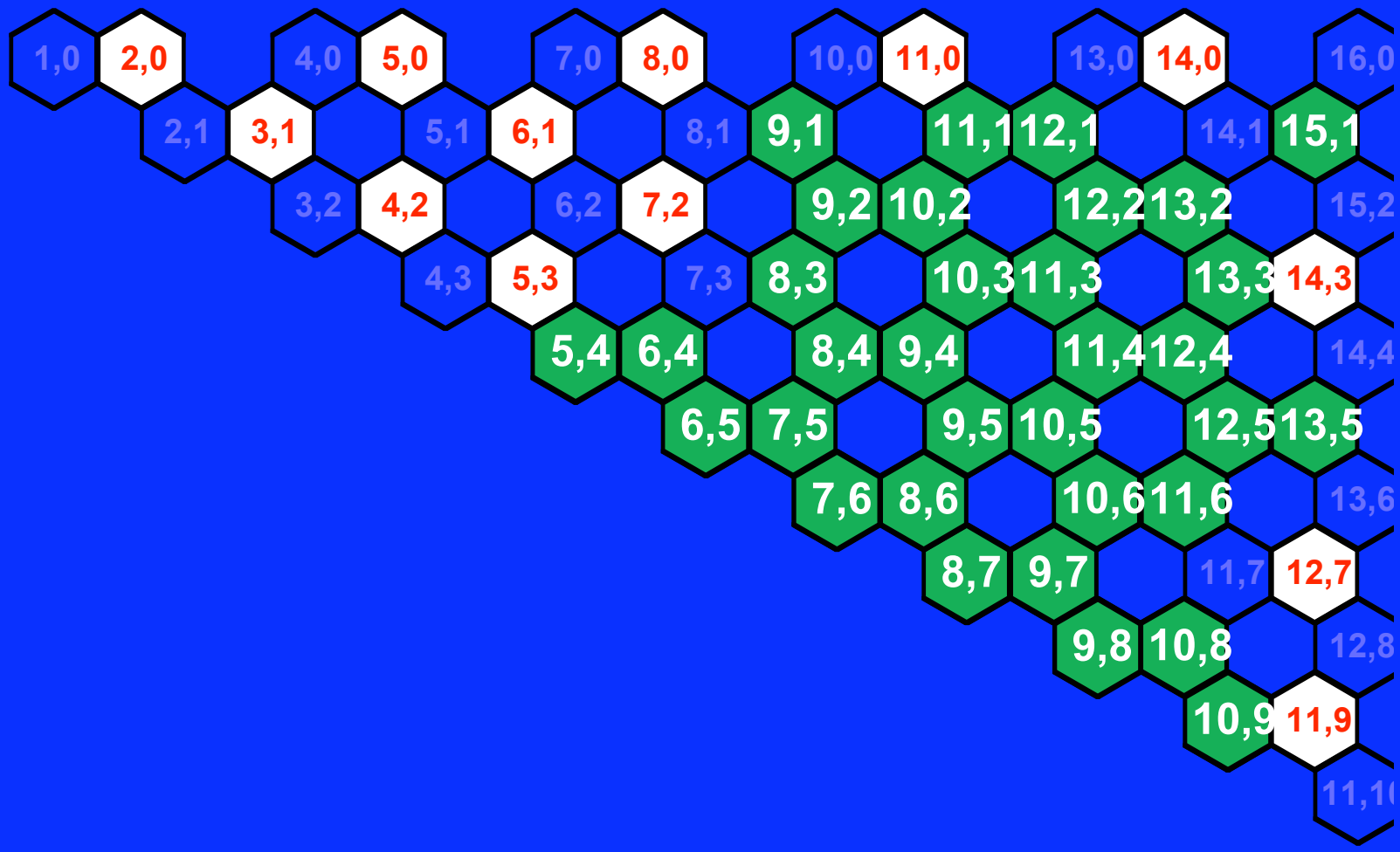



1500
1400
1300
1200
1100
1000
900
Emission wavelength (nm)
300
400
500
600
700
800
Excitation wavelength (nm)

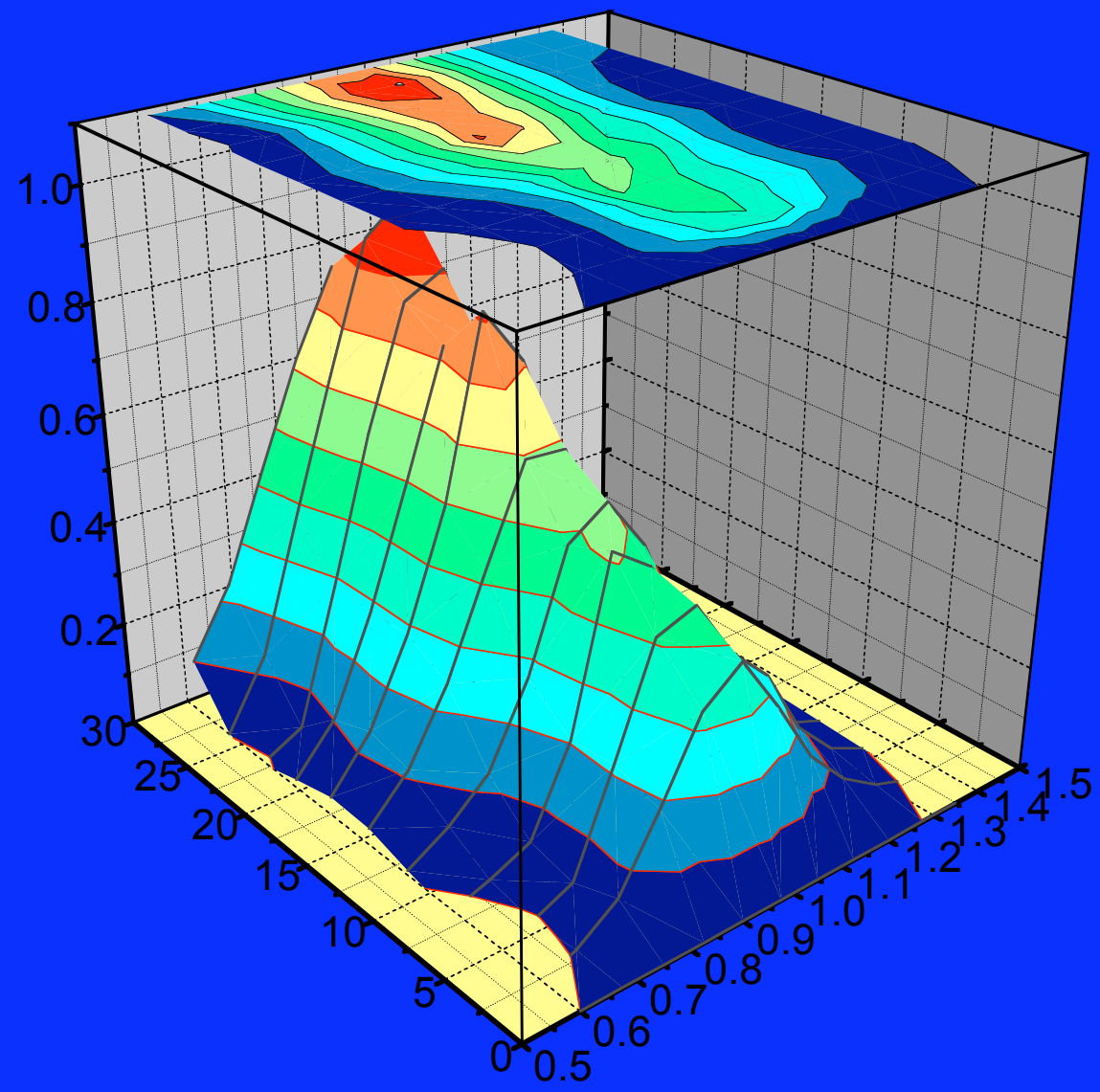
Constructing Nanotubes from a Graphene Sheet

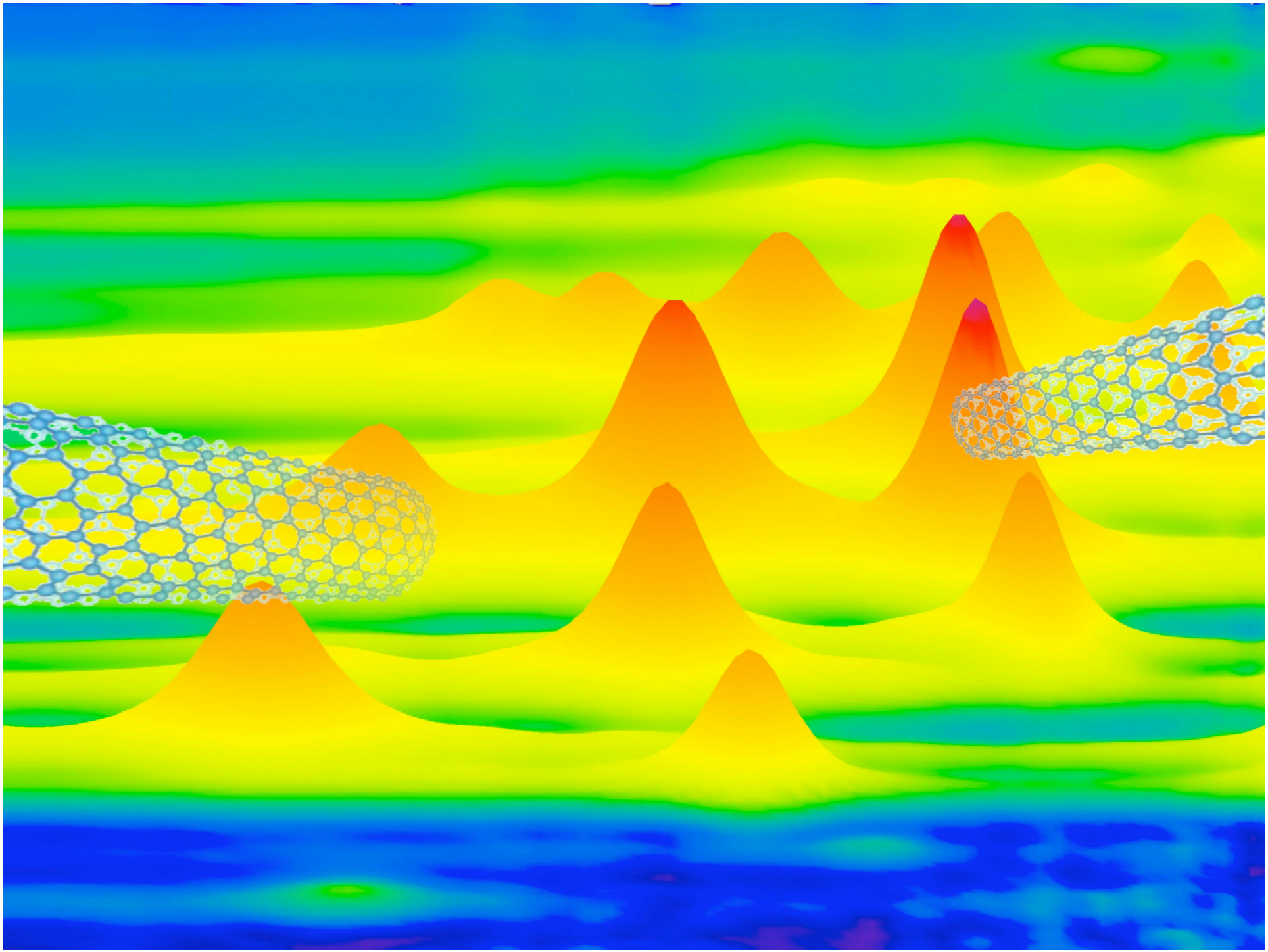


Observed Nanotube Species



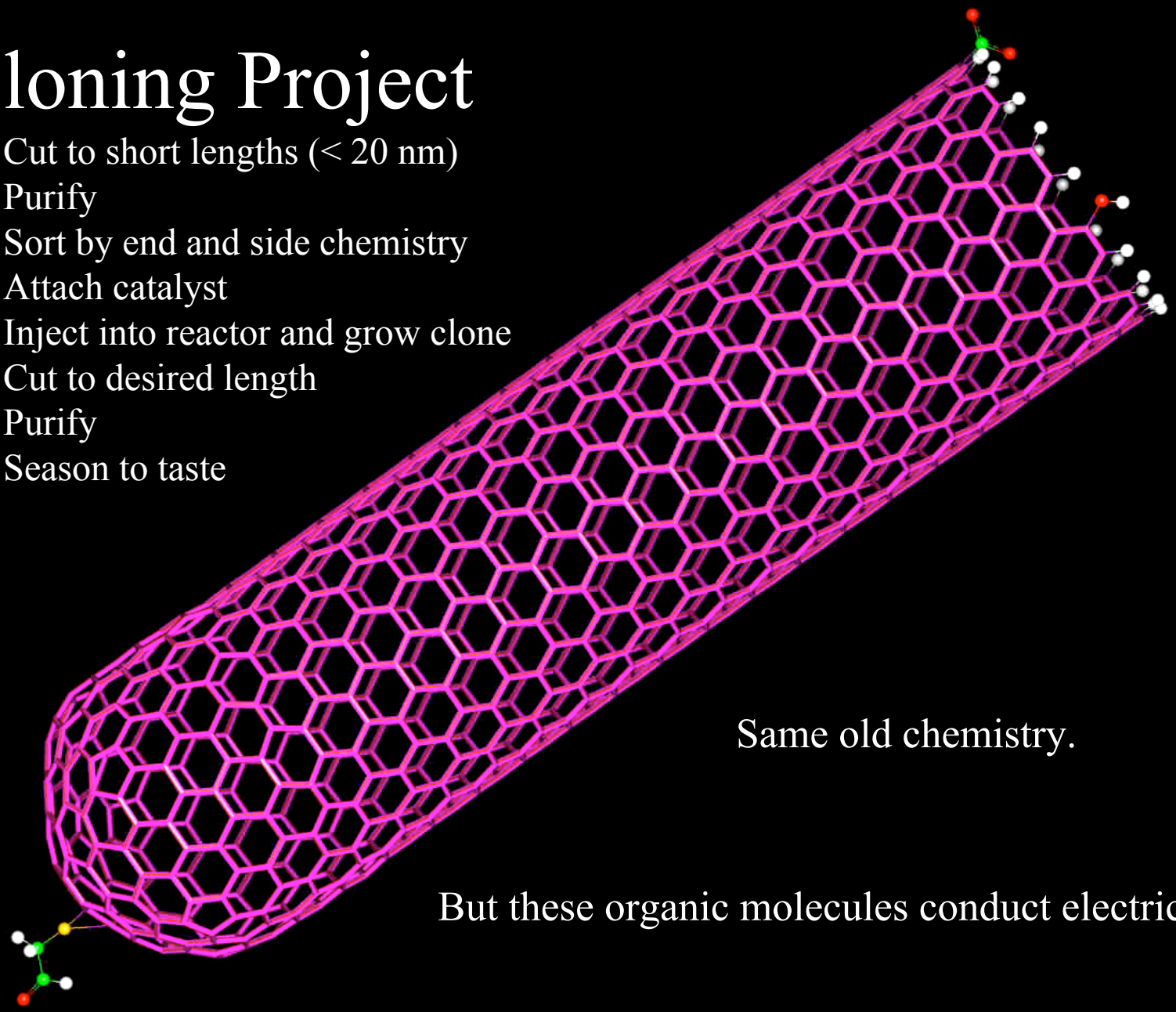
Intensity depends on Diameter and Chirality





Cloning Project

1. Cut to short lengths (< 20 nm)
2. Purify
3. Sort by end and side chemistry
4. Attach catalyst
5. Inject into reactor and grow clone
6. Cut to desired length
7. Purify
8. Season to taste



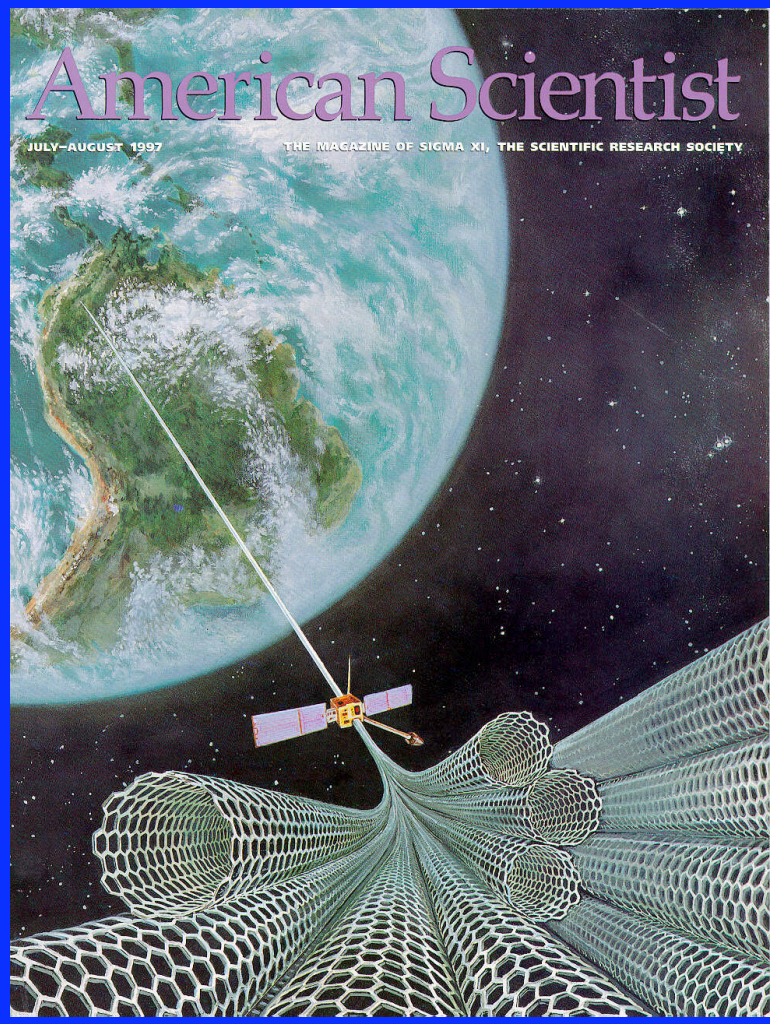
Same old chemistry.

But these organic molecules conduct electricity!

ARMCHAIR WIRE PROJECT

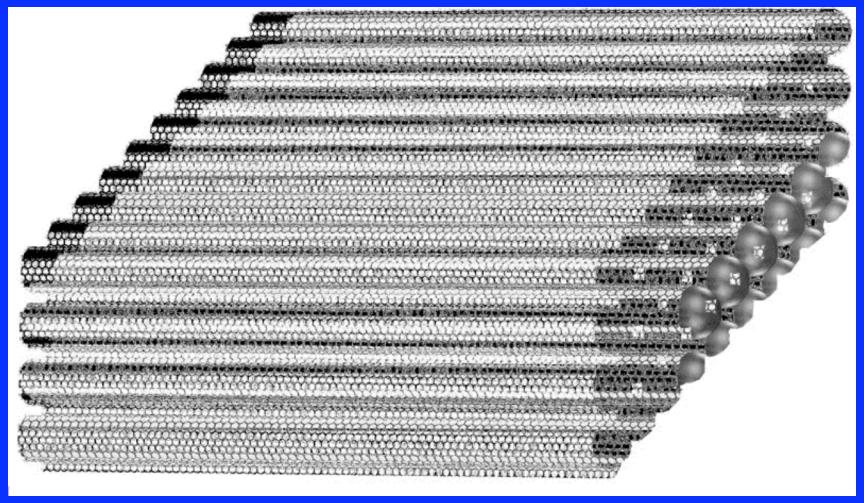
ELECTRICAL CONDUCTIVITY OF COPPER AT 1/6 THE WEIGHT WITH NEGLIGIBLE EDDY CURRENTS

- cut swnt to short lengths
- select out the (n,m) tubes with n=m (the “armchair tubes”)
- grow them to ~ 10 micron lengths
- spin them into continuous fibers



Single Crystal Fullerene Nanotube Arrays

A multifunctional supermaterial



- extreme strength / weight
- high temperature resistance
  (600 C in air, 2000 C in space)
  (for BN tubes ~900 C in air)
- unidirectional thermal conductor
- electromechanical structural component
- unidirectional electrical conductor

-- 0.7 to 1 eV direct band-gap semiconductor
-- or metallic conductor >= copper
-- or (for BN tubes) a 6 eV band-gap insulator

14 Enabling Nanotech Revolutions

1. Photovoltaics -- a revolution to drop cost by 10 to100 fold.

2. H_2 storage -- a revolution in light weight materials for pressure tanks , and/or a new light weight, easily reversible hydrogen chemisorption system

3. Fuel cells -- a revolution to drop the cost by nearly 10 to 100 fold

4. Batteries and supercapacitors -- revolution to improve by 10-100x for automotive and distributed generation applications.

5. Photocatalytic reduction of CO_2 to produce a liquid fuel such as methanol.

6. Direct photoconversion of light + water to produce H_2

7. Super-strong, light weight materials to drop cost to LEO, GEO, and later the moon by > 100 x, to enable huge but low cost light harvesting structures in space; and to improve efficiency of cars, planes, etc.

8. Nanoelectronics to revolutionize computers, sensors and devices.

14 Enabling Nanotech Revolutions

9. High current cables (superconductors, or quantum conductors) with which to rewire the electrical transmission grid, and enable continental, and even worldwide electrical energy transport; and also to replace aluminum and copper wires essentially everywhere -- particularly in the windings of electric motors (especially good if we can eliminate eddy current losses).

10. Thermochemical catalysts to generate H_2 from water that work efficiently at temperatures lower than 900 C.

11. CO_2 mineralization schemes that can work on a vast scale, hopefully starting from basalt and having no waste streams.

12. Nanoelectronics based Robotics with AI to enable construction maintenance of solar structures in space and on the moon; and to enable nuclear reactor maintenance and fuel reprocessing.

13. NanoMaterials/ coatings that will enable vastly lower the cost of deep drilling, to enable HDR (hot dry rock) geothermal heat mining.

14. Nanotech lighting to replace incandescent and fluorescent lights

The biggest single challenge for the next few decades:

ENERGY

for 10^{10} people

- At MINIMUM we need 10 Terawatts (150 M BOE/day) from some new clean energy source by 2050
- For worldwide peace and prosperity we need it to be cheap.
- We simply can not do this with current technology.
- We need Boys and Girls to enter Physical Science and Engineering as they did after Sputnik.
- Inspire in them a sense of MISSION (BE A SCIENTIST SAVE THE WORLD)
- We need a bold new APOLLO PROGRAM to find the NEW ENERGY TECHNOLOGY

Be a Scientist
Save the World

University Professor Lecture on Energy
Rice University , January 23, 2003
[now available on www.ruf.rice.edu/~smalleyg/res.htm]