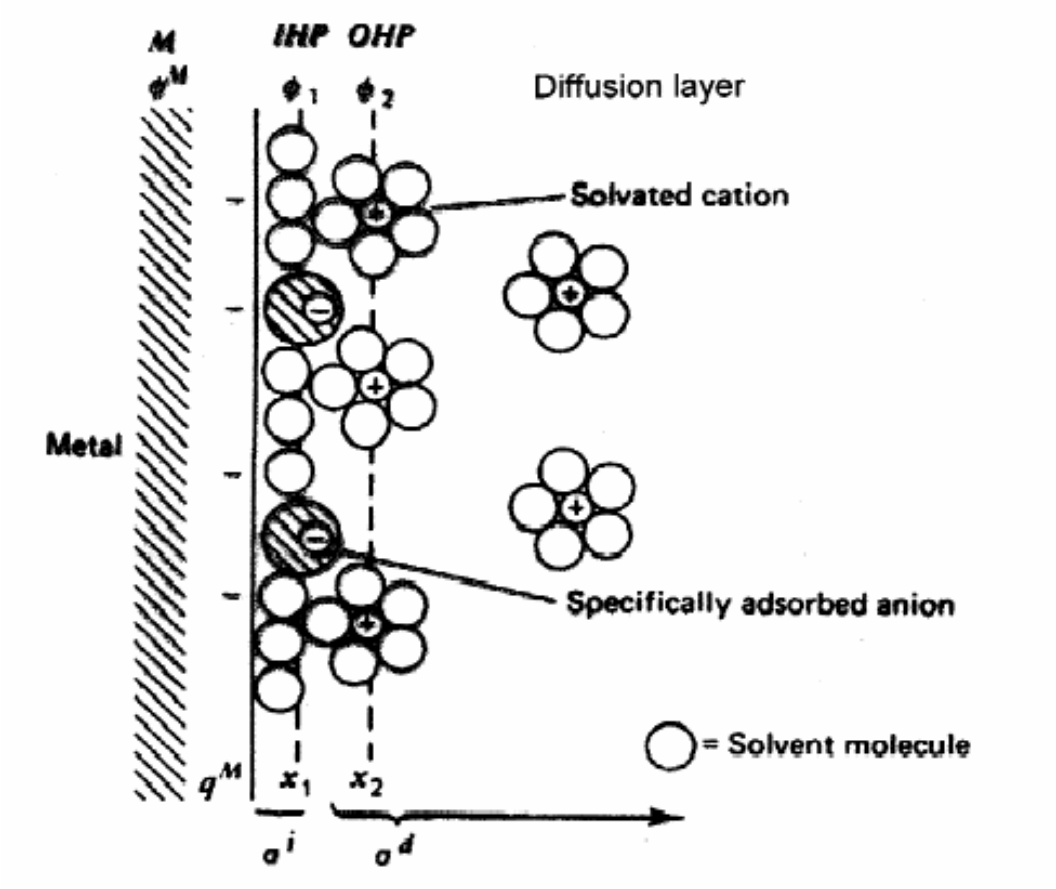
# Electrochemical Supercapacitor

AKA Electrical Double Layer Capacitor

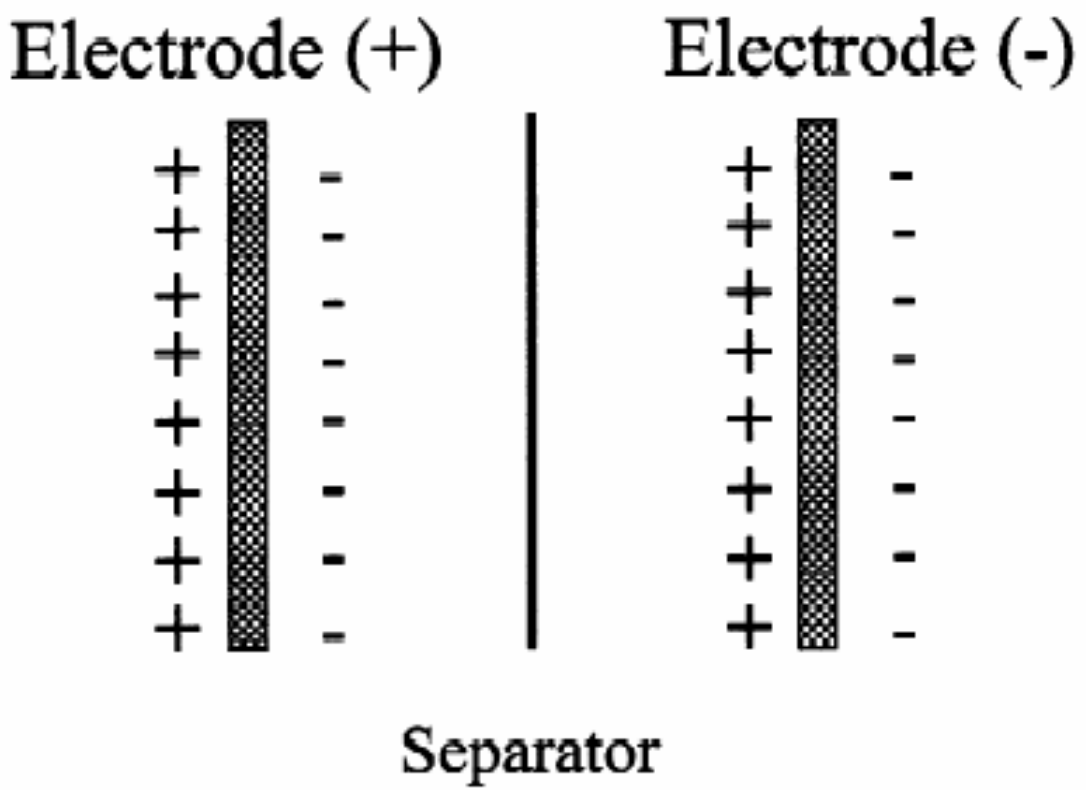
- Basic principle
- Electrode materials
- Electrolytes
- Similar technology (Electrolytic capacitors)

# Principles

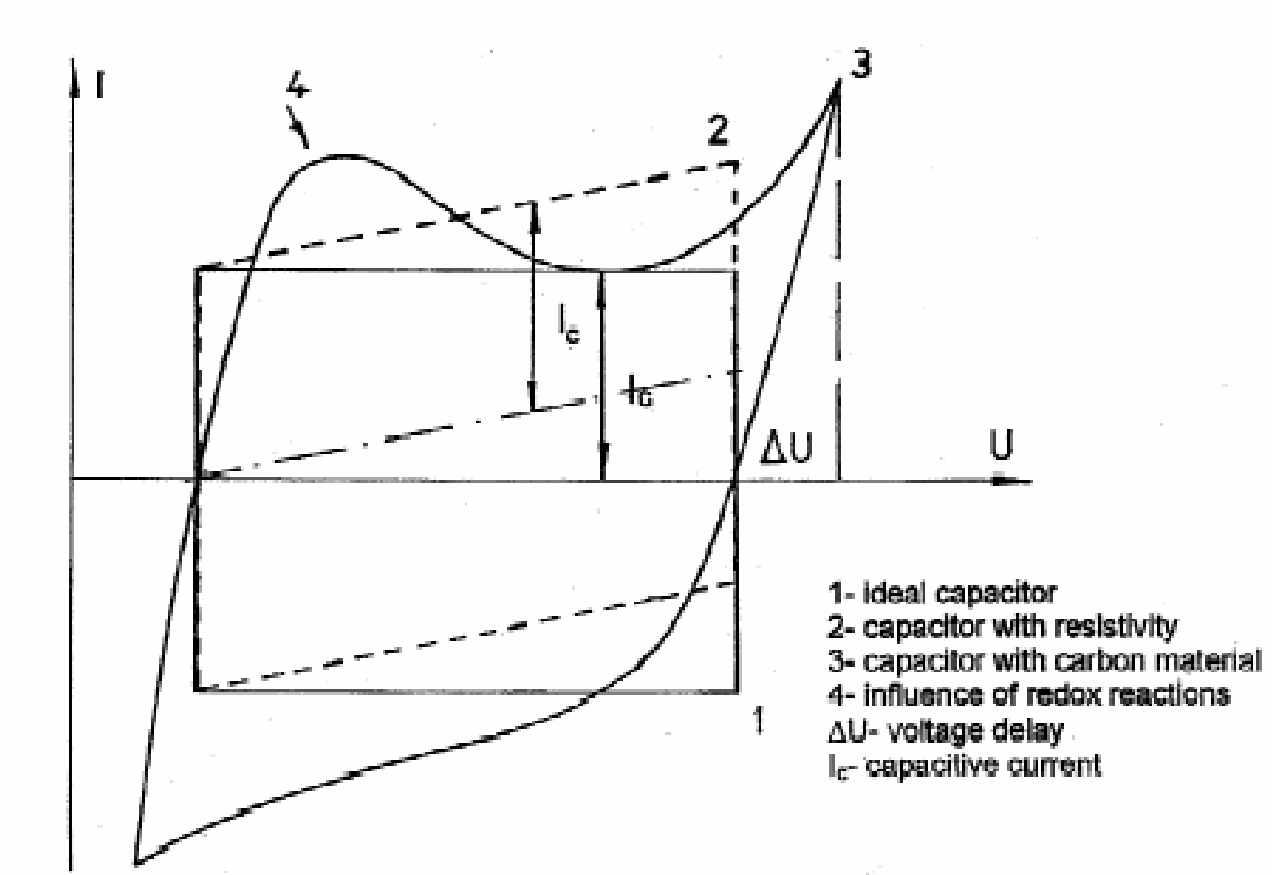
- Electrical double layer



# Schematic of a Supercapacitor



# Cyclic Voltammetry




Cyclic voltammetry of supercapacitors:

# The electrode materials

Typically based on activated carbons

1. AC paste + rubber binder
2. AC cloths/fabrics/non-woven
3. Carbon aerogel
4. Other carbon nanoforms (tubes/balls…)

Other materials with Redox boost

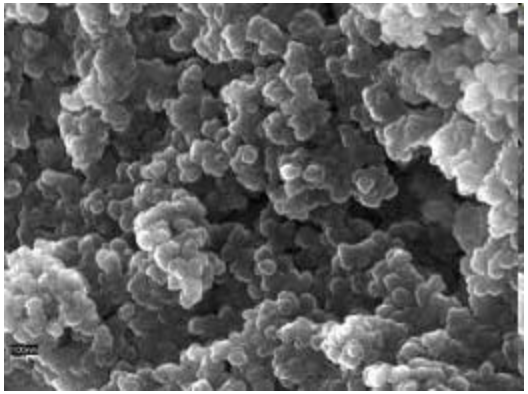
for example $RuO_2$

# AC: examples

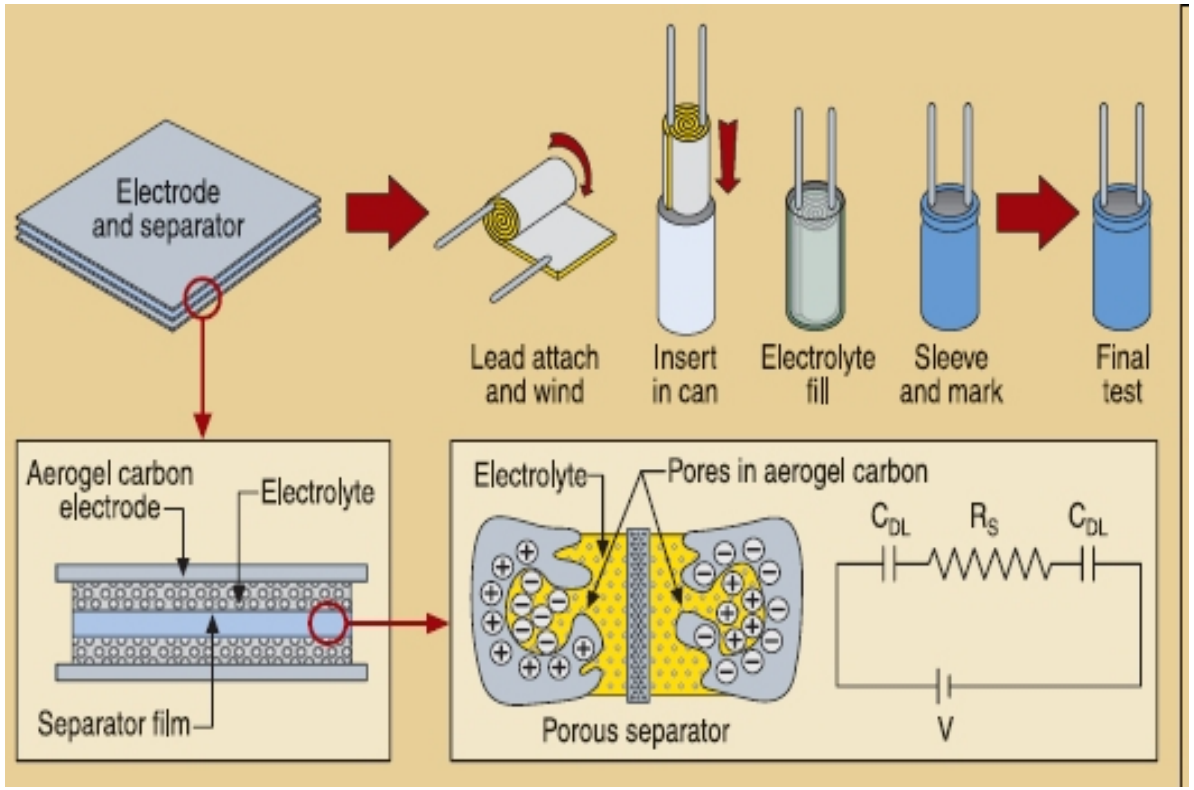
AC cloth

# AC examples: aerogel

Aerogel of SiO2



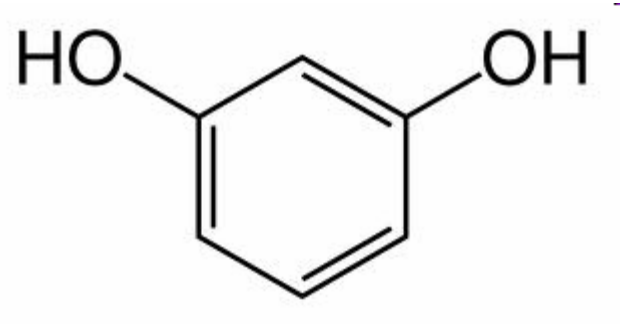
Aerogel of Carbon SEM



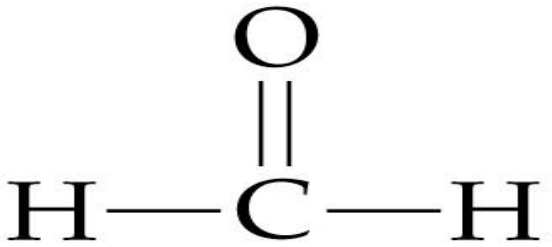

How to make a C aerogel capacitor

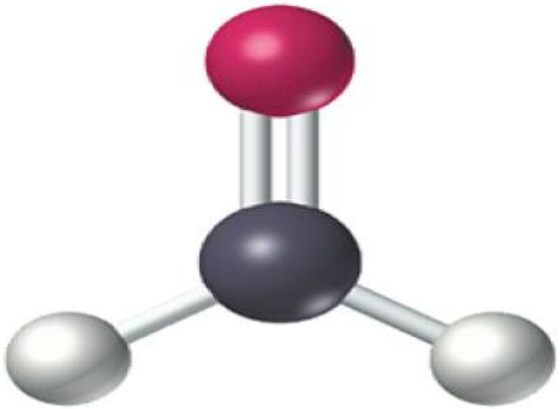
# Making of Carbon Aerogel

- Starting material: Resorcinol + Formaldehyde (RF)
- Resorcinol is like phenol
- The process is like making phenol formaldehyde resin
- Resorcinol formaldehyde is a wood glue




Resorcinol

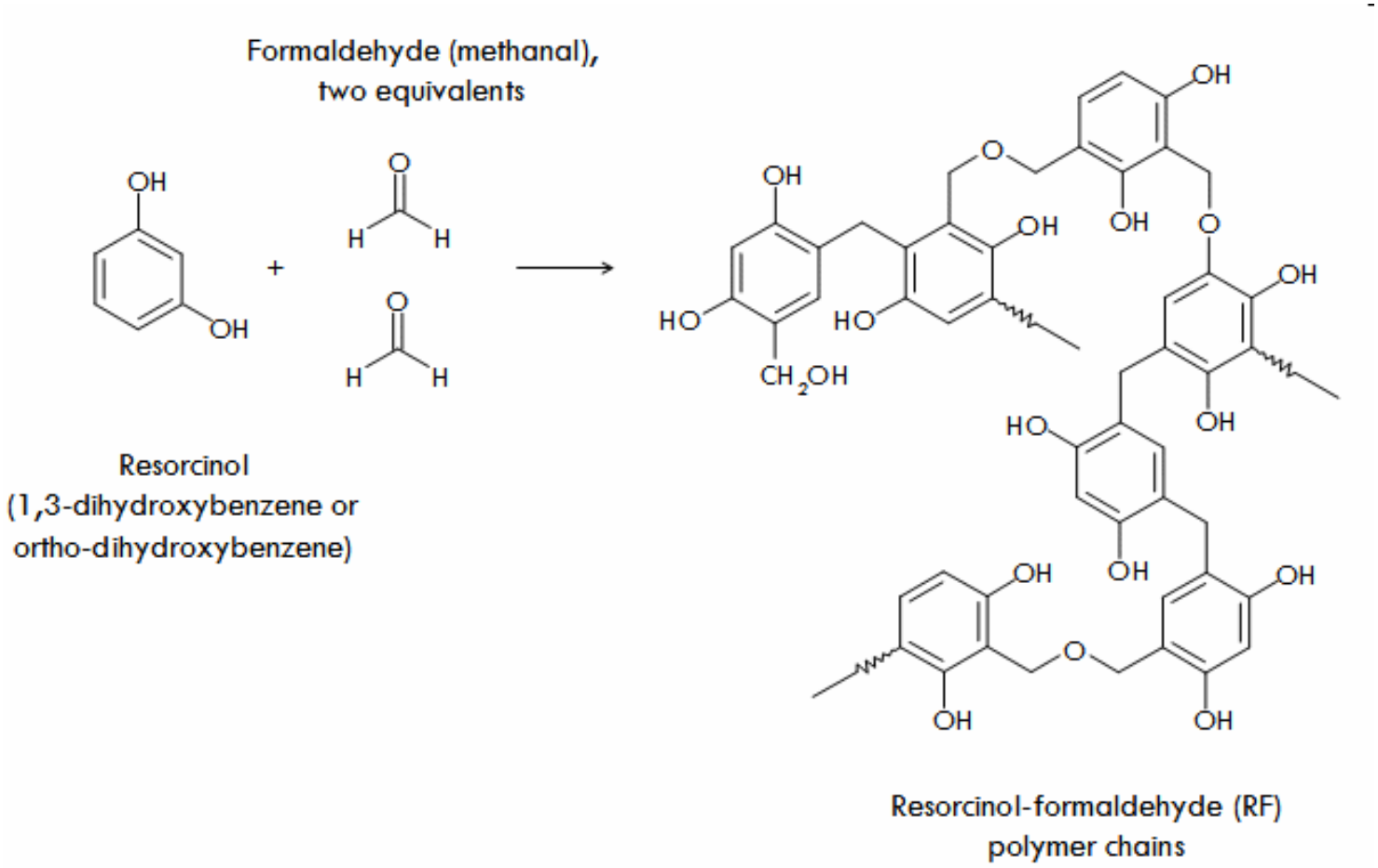


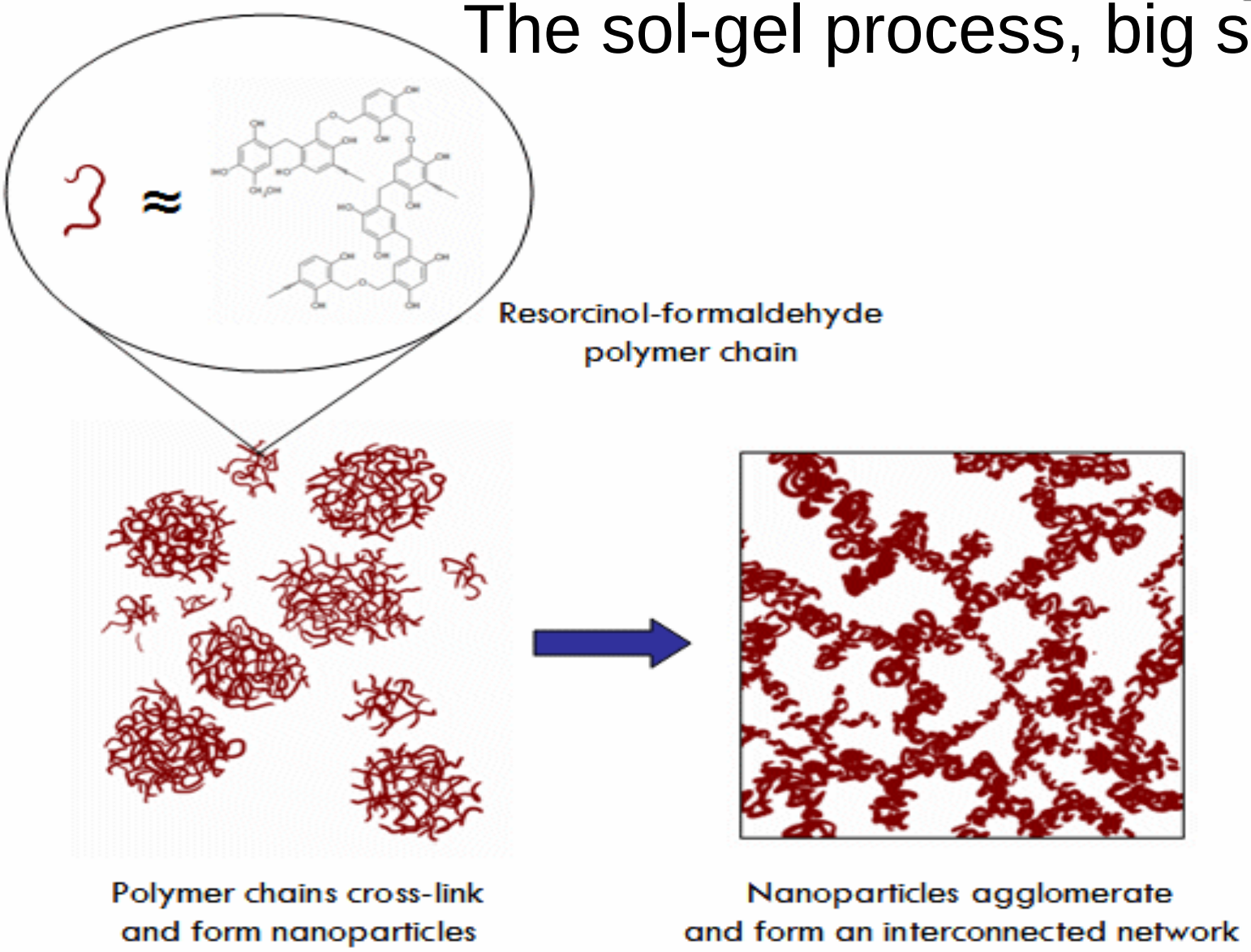
Formaldehyde

# Making of Carbon Aerogel

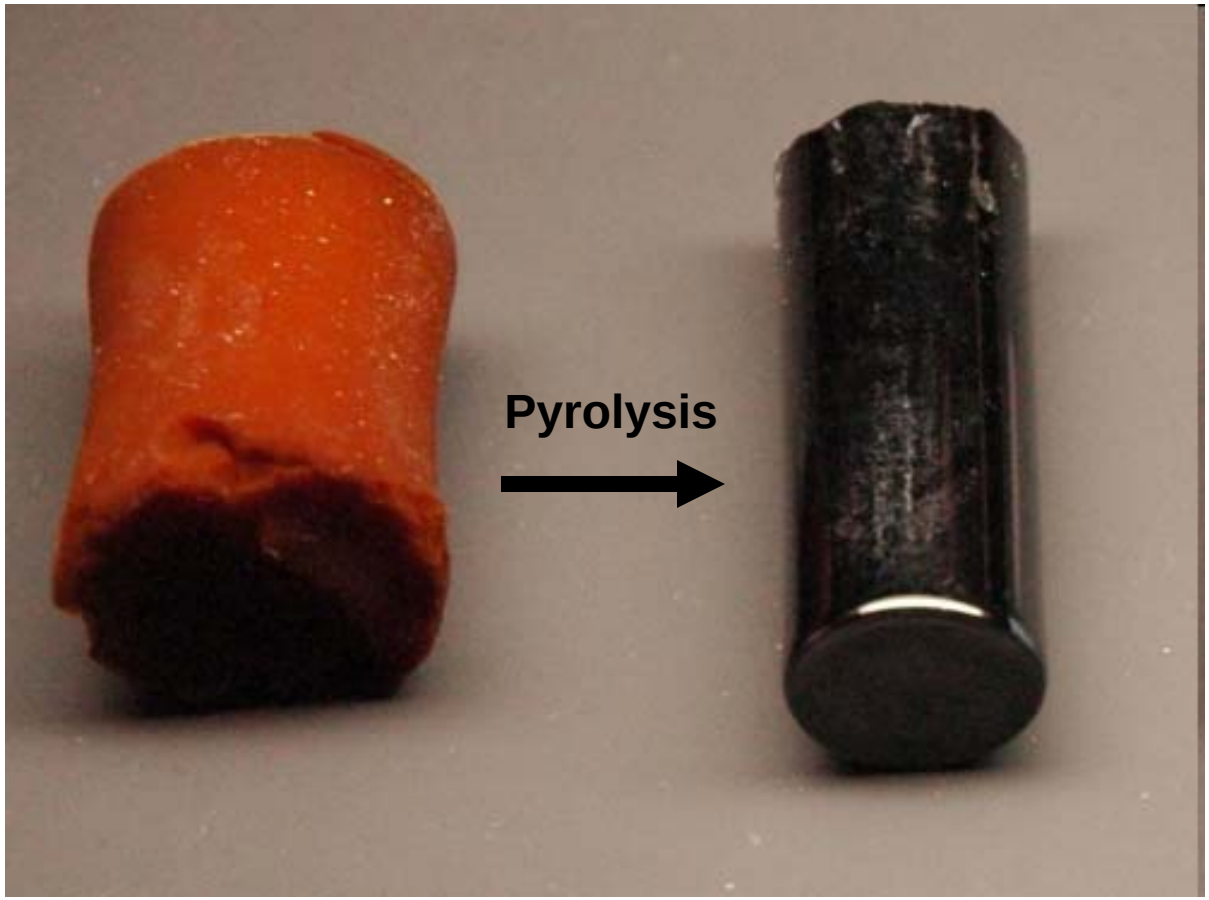
The sol-gel process



# The sol-gel process, big scale



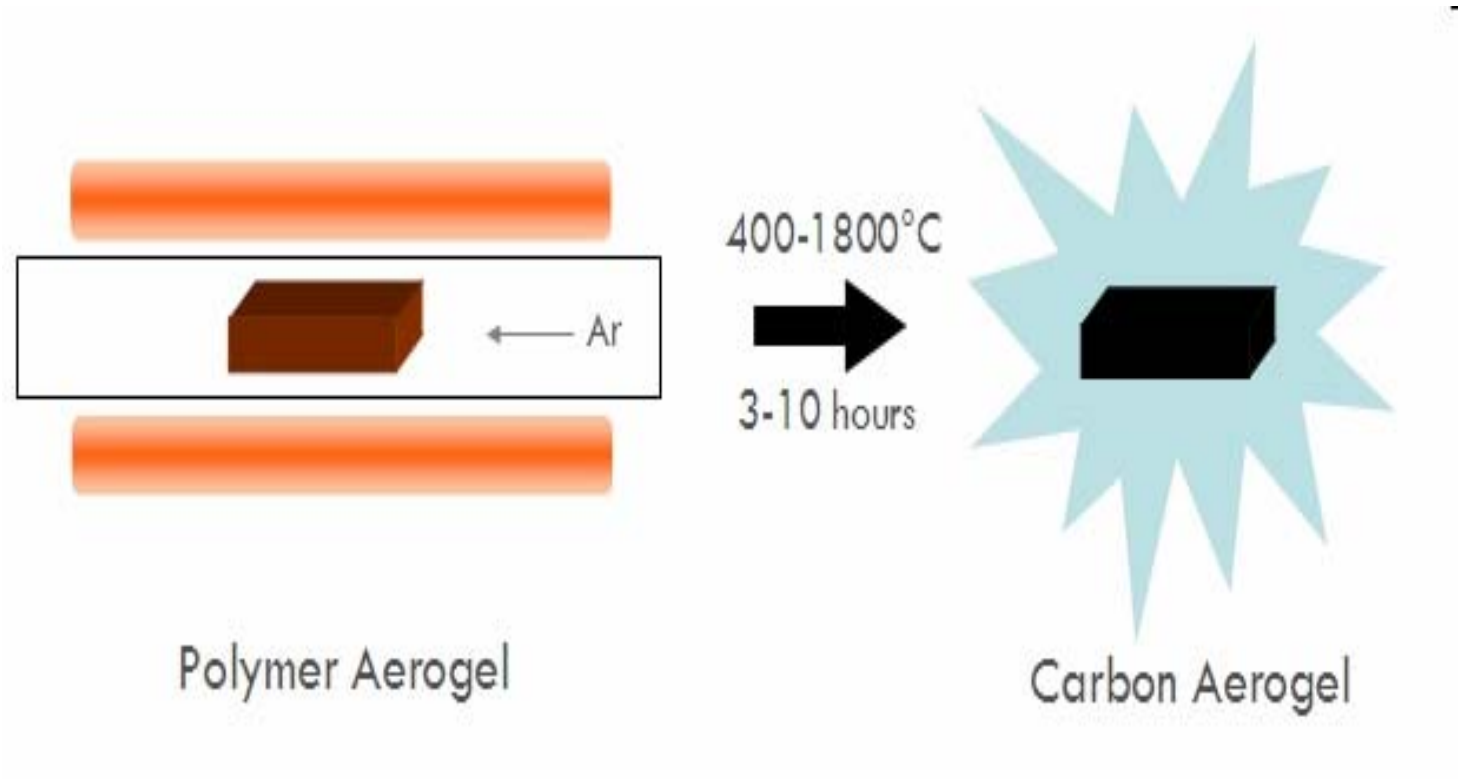
# RF aerogel vs carbon aerogel




A resorcinol-formaldehyde polymer aerogel (left) and a carbon aerrogel (right)

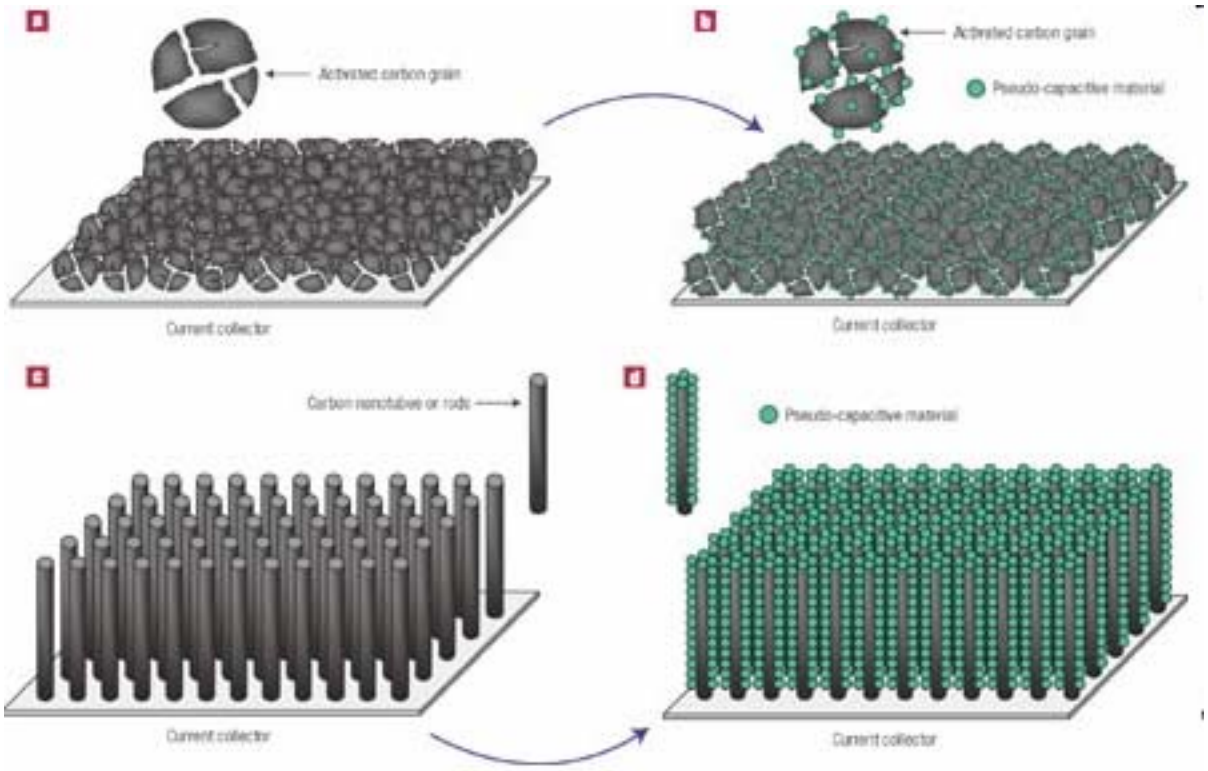
# From RF to carbon aerogel

Pyrolysis after a CO2 supercritical drying



# PseudoUltracapacitor

Often called Asymmetric Ultra(Super)-capacitor with RuO2 on one side to improve the specific energy



# PseudoUltracapacitor materials

| | Electrode material | Electrolyte | Working voltage (V) | Specific capacitance (F/g) |
|---|---|---|---|---|
| Carbon-based | Activated carbon (AC) [52] | 1 M $Et_4NBF_4$ + PC | 1.5 | 40 |
| | Graphite [45] | 1 M $Et_4NBF_4$ + PC | 3.0 | 12 |
| | Carbon aerogels (CAGs) [42] | 1.5 M $Et_3MeNBF_4$ + PC | 3.0 | 160 |
| | Mesoporous carbon [20] | 30 wt% KOH | 0.9 | 180 |
| | Meso/macroporous carbon [53] | 6 M KOH | 0.8 | 130 |
| | $C_{60}$-loaded AC fibe [19] | 0.5 mol/L $H_2SO_4$ | 1.0 | 172 |
| | AC fiber cloth [47] | 6 mol/L KOH | 1.0 | 208 |
| | Single-walled CNTs [22] | EMITFSI | 2.3 | 50 |
| | Multi-walled CNTs sheet [12] | 1.96 M $TEMABF_4$ + PC | 2.5 | 13 |
| | CNTs/polypyrrole (PPy)/$MnO_2$ [49] | 1.0 M $Na_2SO_4$ | 0.9 | 281 |
| Transition metal oxide | $RuO_2 \cdot H_2O$ [13] | 0.5 M $H_2SO_4$ | 1.0 | 650 |
| | Ruthenic acid nanosheet/Au [54] | 0.5 M $H_2SO_4$ | 1.2 | 620 |
| | $H_{0.2}RuO_{2.1} \cdot nH_2O$ [28] | 0.5 M $H_2SO_4$ | 1.2 | 390 |
| | $RuO_2$/carbon [55] | PVA hydrogel | 0.8 | 1000 |
| | Amorphous $Ru_{1-y}Cr_yO_2/TiO_2$ [56] | 1 mol/L KOH | 0.9 | 1272 |
| | $MnO_2$ [16] | 0.5 M $K_2SO_4$ | 0.8 | 261 |
| | $MnO_2$/AC [57] | 0.65 M $K_2SO_4$ | 2.2 | 29 |
| | $SnO_2$/carbon aerogel [58] | 1 M $H_2SO_4$ | 1.0 | 68 |
| | $Ni(OH)_2$ [18] | 3% KOH | 0.8 | 578 |
| | $Ni(OH)_2$/AC [59] | 6 mol/L KOH | 0.9 | 194 |
| | Cobalt-nickel oxides/CNTs [14] | 1 M KOH | 1.0 | 569 |
| | Nickel-based mischmetal/AC [60] | BMIM-$PF_6$ | 3.0 | 357 |
| | $Mo_2N/Ta_2O_5$ [5] | 3.5 mol/L $H_2SO_4$ | 0.8 | 106 |
| | WC/carbon [61] | 1 mol/L $H_2SO_4$ | 0.9 | 477 |

# Electrolyte

Two types

1. Aqueous (Safe, limited to 1.4V)
2. Non-aqueous (Expensive, voltage up to 3~4V, specific energy then can be 6 times more)

# Electrolyte

Chemical compositions

1. Aqueous (water solution of sulfuric acid or potassium hydroxide)
2. Non-aqueous:
   Solvent is typically a polycarbonate
   electrolyte conductor typically is

   Et4NBF4 (Tetraethylammonium tetrafluoroborate)

# Performance