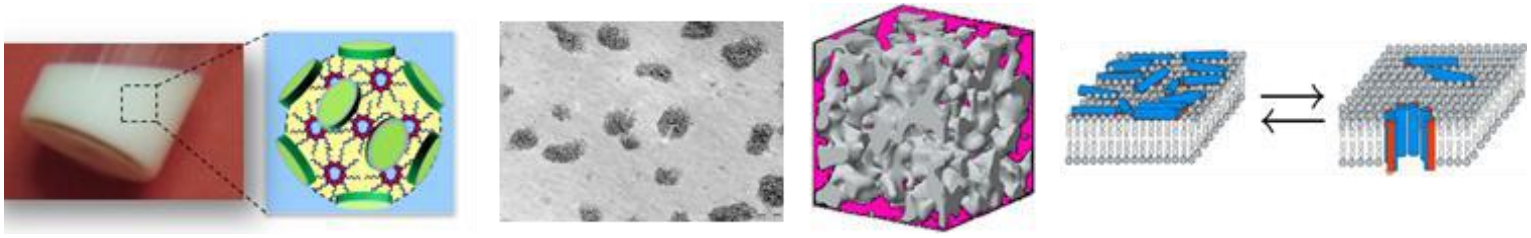
Soft Matter Revue

Journée de la Fédération Française de Diffusion Neutronique 2FDN

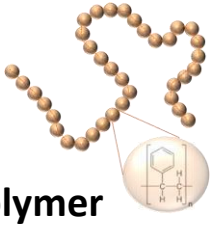
16 Mai 2017



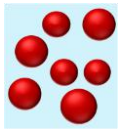
What is Soft Matter?

An elementary Brick

~1-10 nm



Polymer



Colloids

Simple liquid

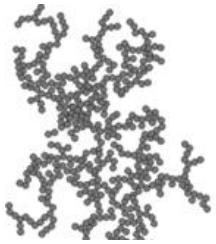
Surfactant

~ $k_B T$

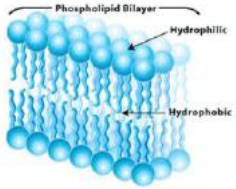
T°,
P, [c],
B_0, E_0…

Complex forms/structure

~100-1000 nm



Cluster



Lamellar phase

Strong reorganizations under weak sollicitations
Surface/interfaces
Poly-dispersity

Macroscopic Properties

Reinforcement

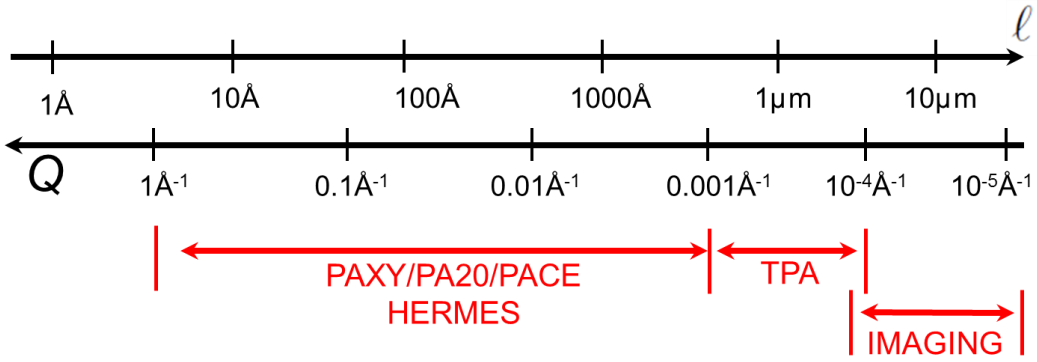
Viscosity

Fundamental questions

Applications

Neutrons for Soft Matter

Neutron diffraction techniques offer a large suite of **complementary instruments** that allow to characterize the structure in **volume** (**SANS**, **Imaging**) and at the **interfaces** (**Reflectivity**) along a broad **multi-length scale**:



Individual and **collective motions** can be determined with **spin echo** (Muses), **back-Scattering** (IN13) and **Time-of-Fligth** (IN6/Sharp) over a **broad range of typical times**.

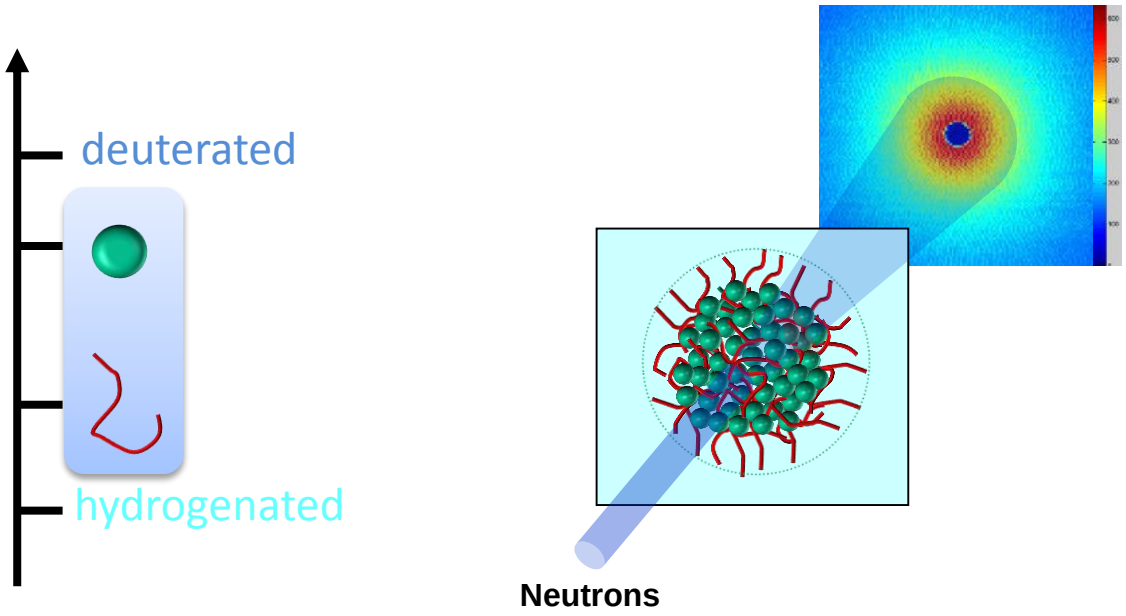
Light elements, **non-destructive** (biological samples), **large amount** of material ~cm^3.

A large variety and versatile series of **sample environnements** are available to change the conditions *in-situ* (T°, P, pH, [c]…) or to perform *in-situ* sollicitations (magnetic/electric field, shear/stretchted/couette cells, humidity chamber…)

Multi-scale Structure & Dynamics

Neutron Contrast Variation

We can **change** (increase) the contrast by **isotopic substitution** and elucidate complex structures for **multi-component** systems by **contrast matching**.



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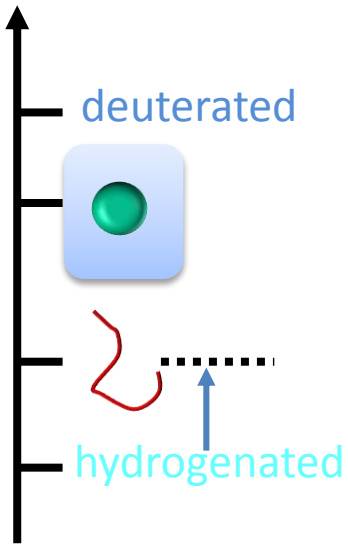

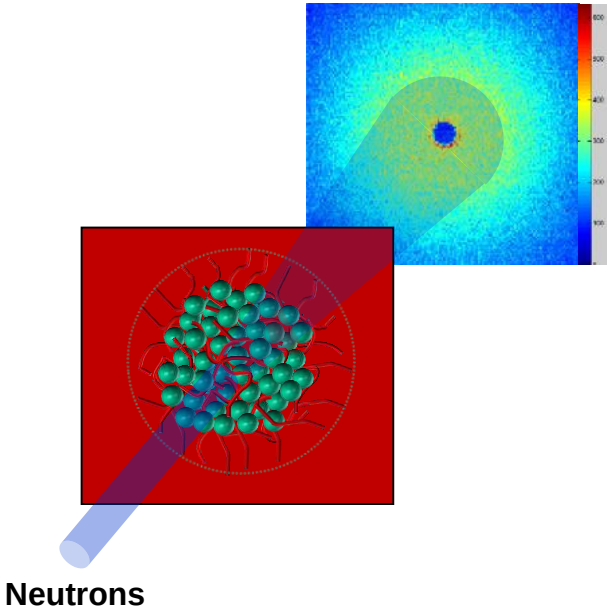

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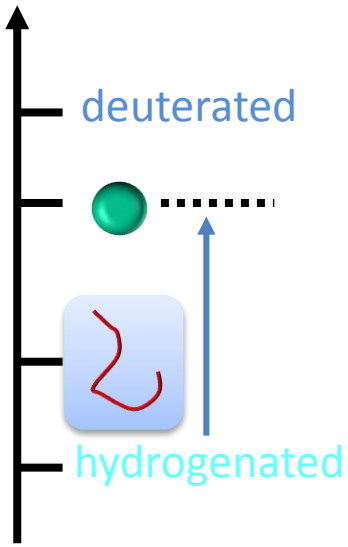

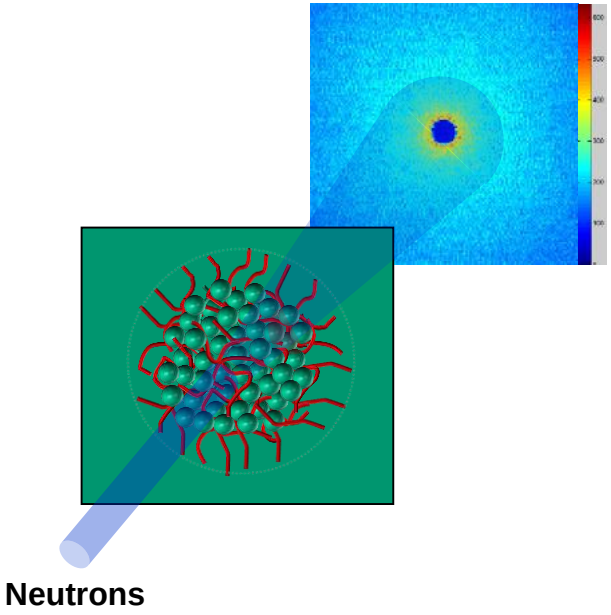

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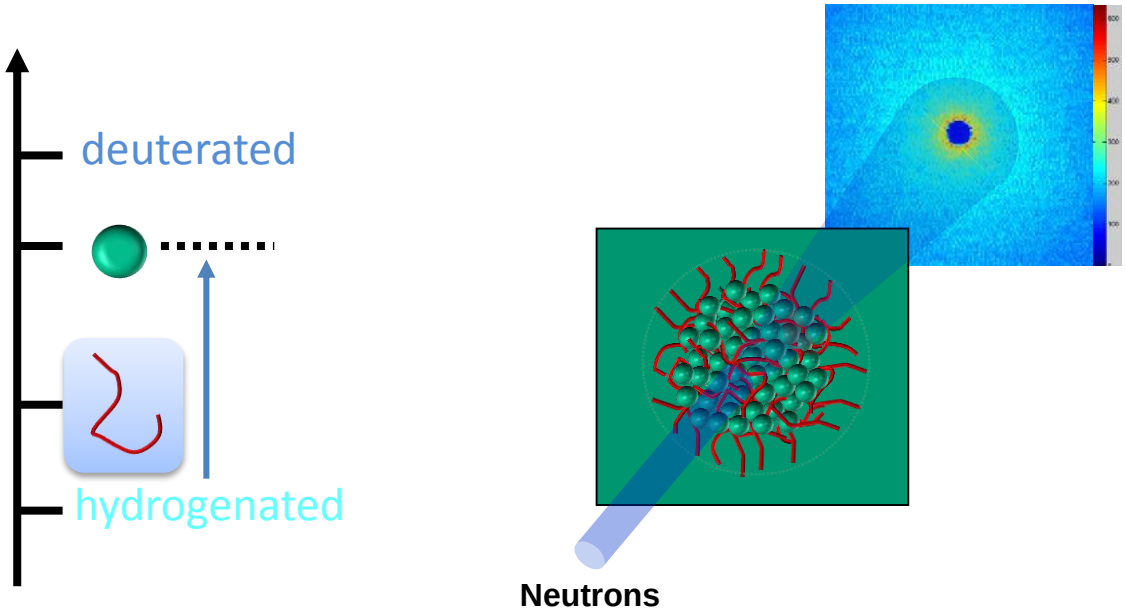
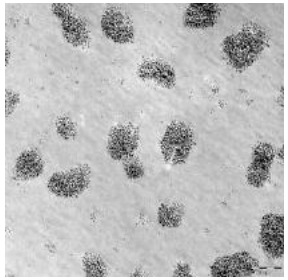


An unique tool for multi-component systems

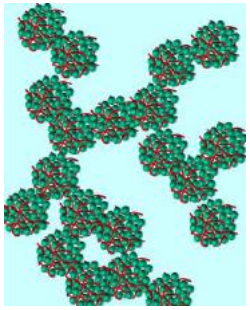
Complementarity with **RX** (SAXS, reflectivity), **electronic microscopy**, **light scattering**

Soft Matter and Biophysique

Nanocomposites

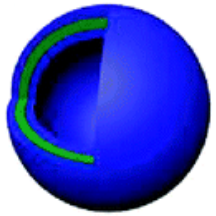


Electrostatic complexes



Food science

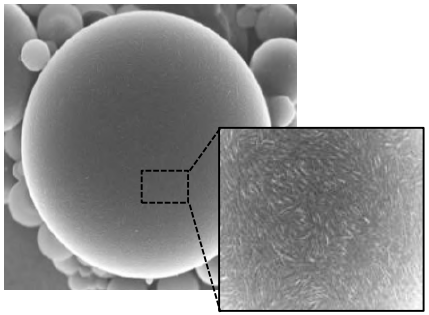
Vesicles



Drying processes

Responsive NPs

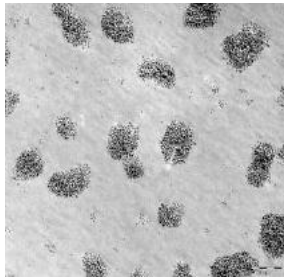
Emulsions, mousses



Polymers, Copolymer, Nanoparticles and Surfactants

Soft Matter and Biophysique

Nanocomposites



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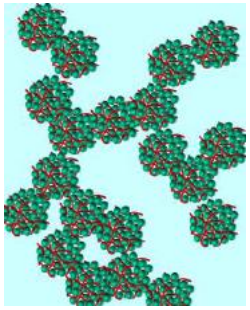

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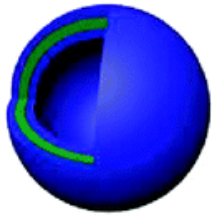

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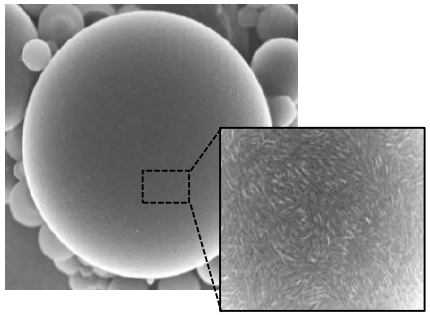
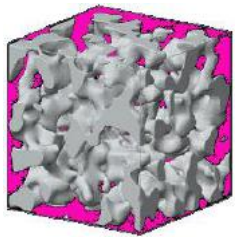


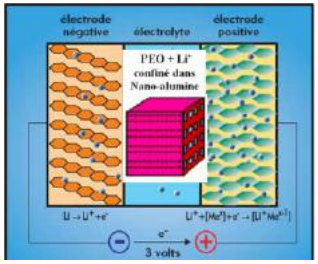
Polymers, Copolymer, Nanoparticles and Surfactants

Soft Matter and Biophysique

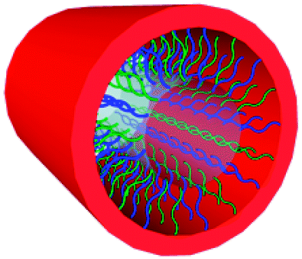
Interfacial water



Confined IL

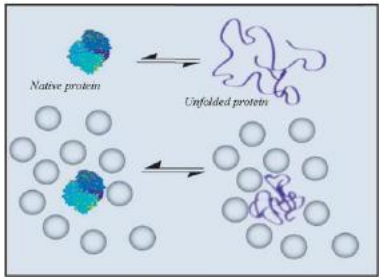


Grafted Nanomembranes

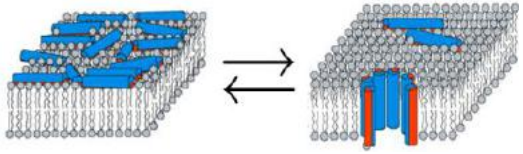


Mesoporous materials

Crowding



Membranes

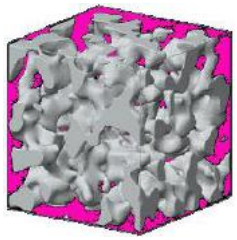


HFQ protein

Confinement and bio-systems

Soft Matter and Biophysique

Interfacial water



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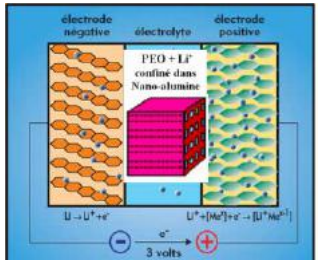

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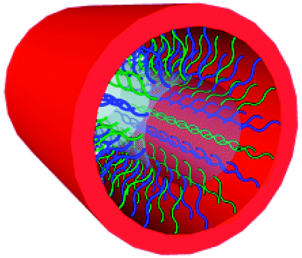
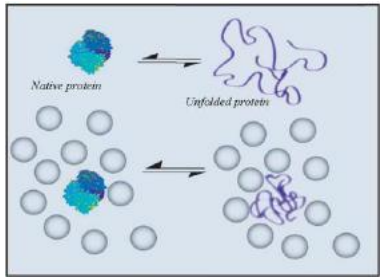
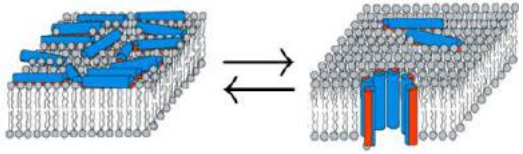


Mesoporous materials

Crowding



Membranes



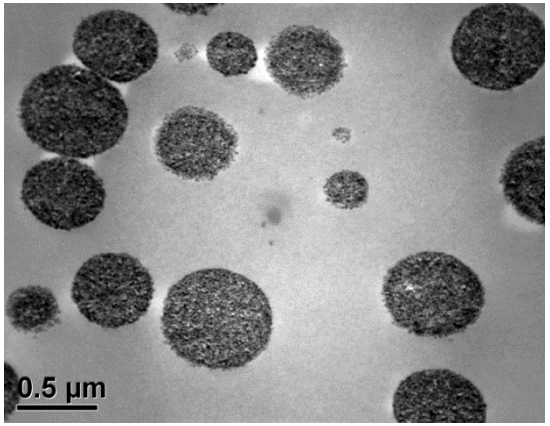
HFQ protein

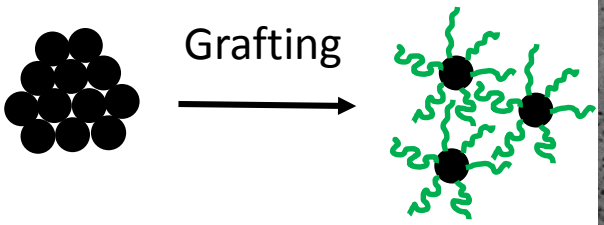
Confinement and bio-systems

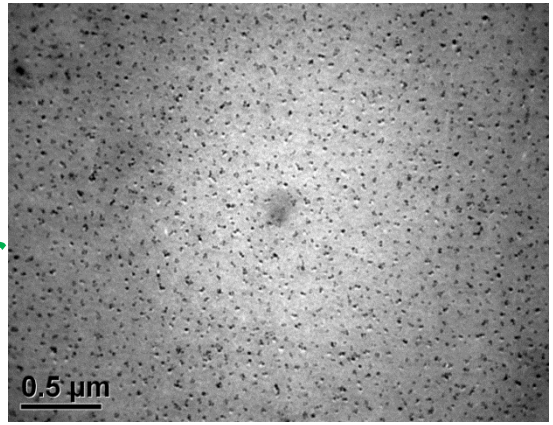
Nanocomposites

Grafted Chain Conformation

Cost-effective methods to disperse nanoparticles

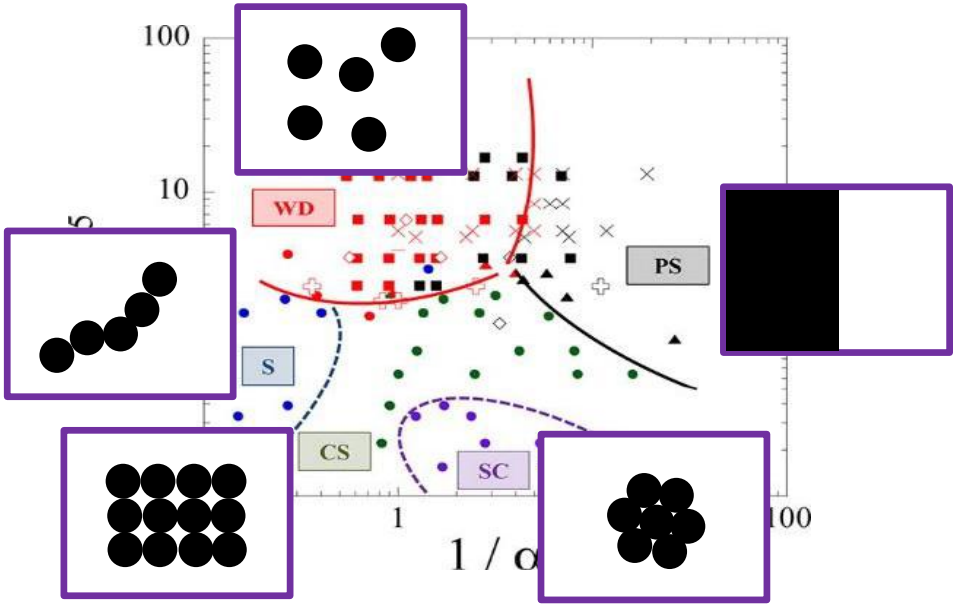






Control nanoparticle dispersion states

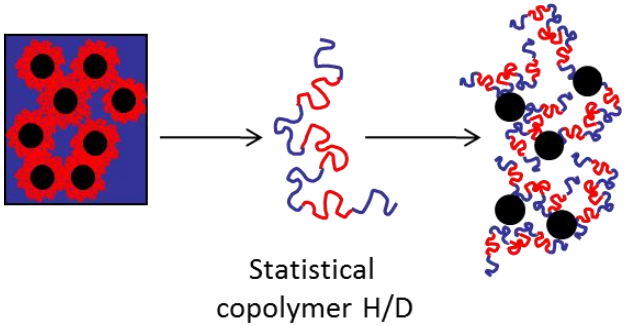
Uniform particle dispersion
Connected structures



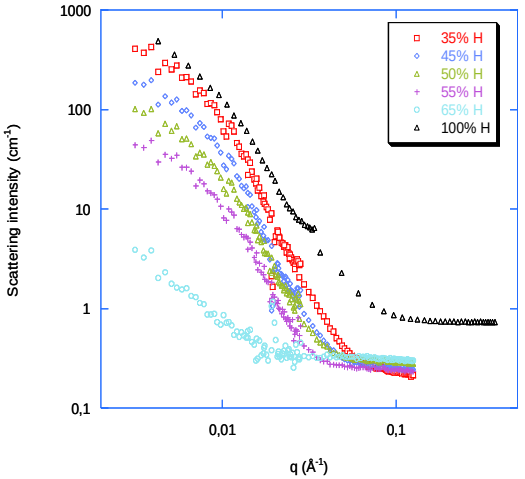
Chevigny Macromolecules 2011
Robbes Macromolecules 2012
Kumar Macromolecules 2013

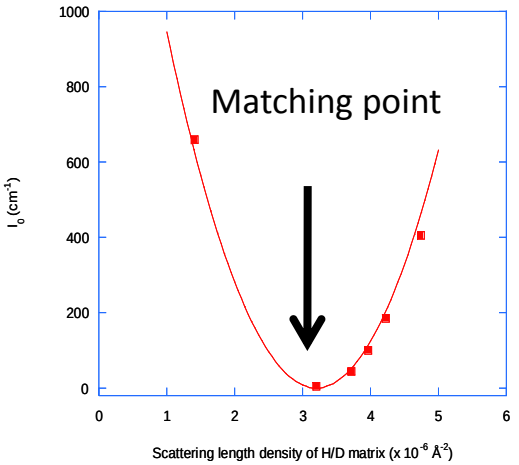
Nanocomposites

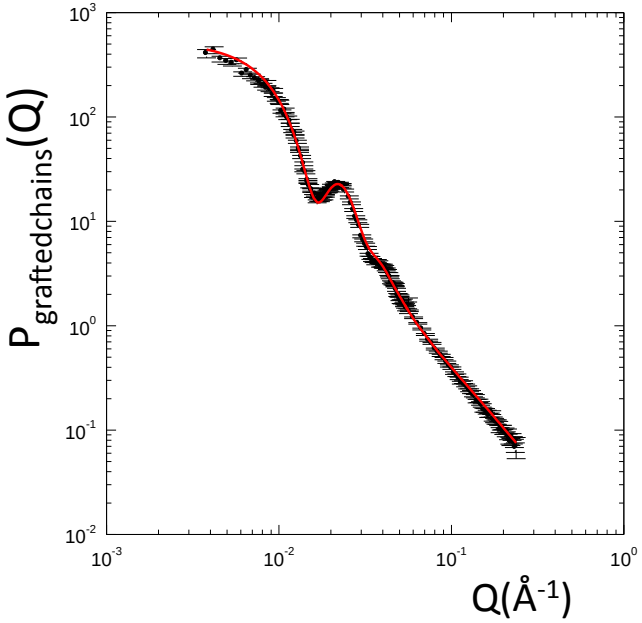
Grafted Chain Conformation

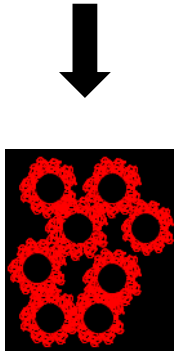


Selective deuteration







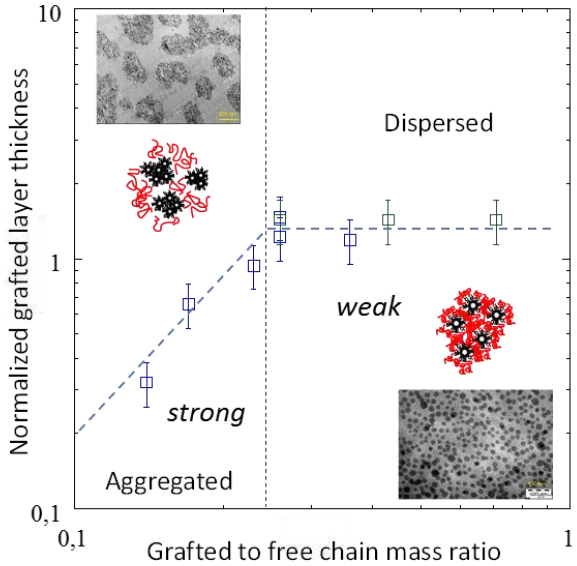


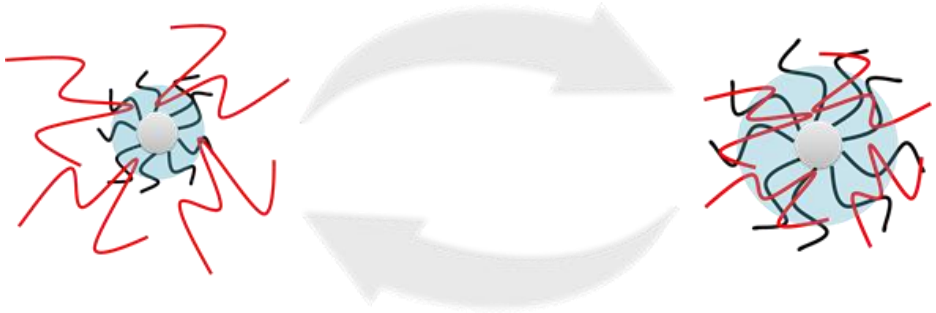
« Black matrix » that matches the silica contribution in the melt

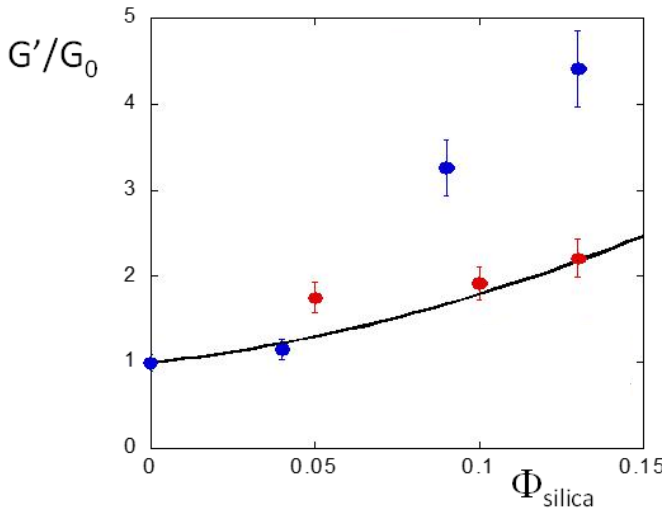
Chevigny Macromolecules 2010

Nanocomposites

Grafted Chain Conformation







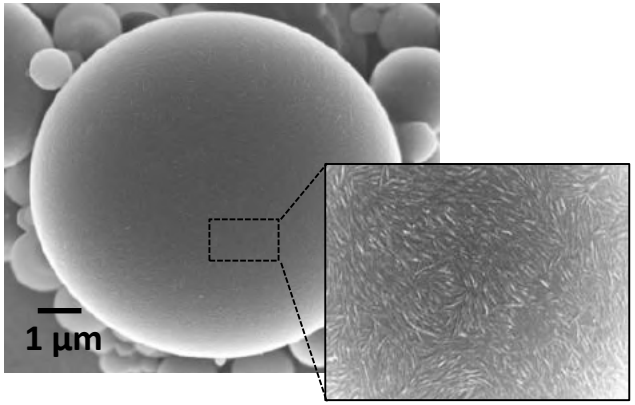
A **new interaction**, entanglement degree between grafted and free chains, that drives reinforcement

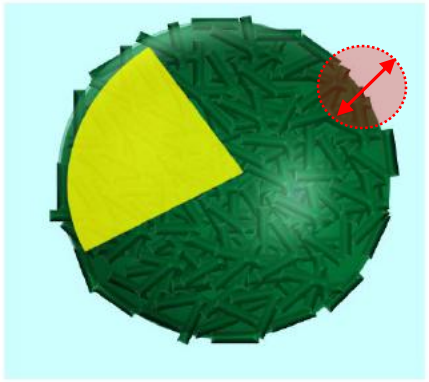
Collaborations

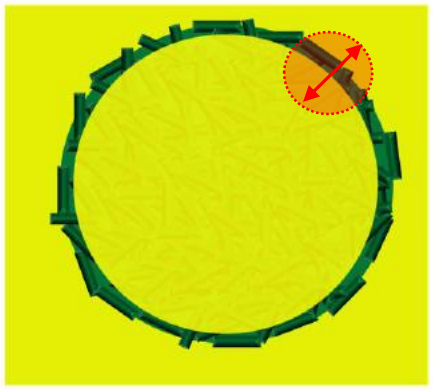
Chevigny Macromolecules 2010

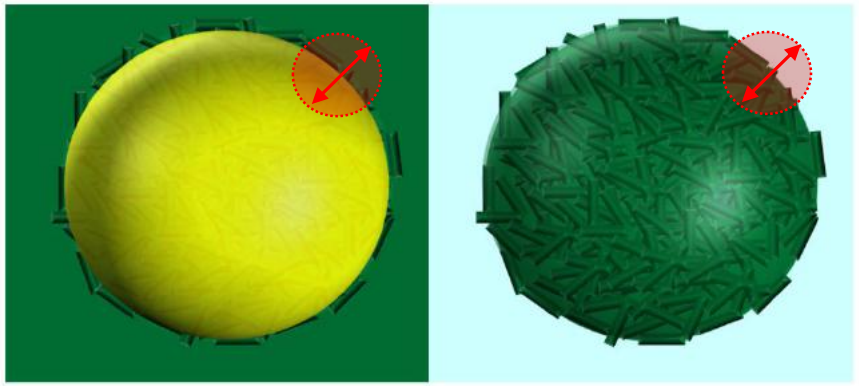
Emulsions

O/W stabilized with cellulose whiskers









Infinite plan : $I(cm^{-1}) \propto q^{-2}$

Porod law : $I(cm^{-1}) \propto q^{-4}$

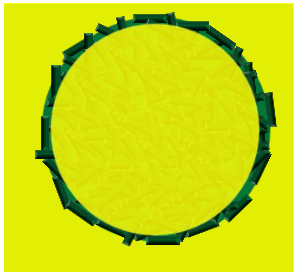
Direct measurement of the interfacial thickness

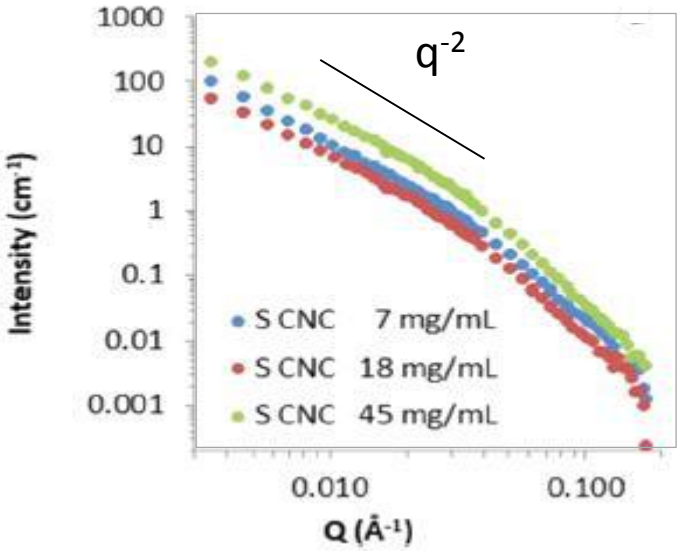
Specific surface, roughness

Cherhal et al, Biomacromolecules, 2016

Emulsions

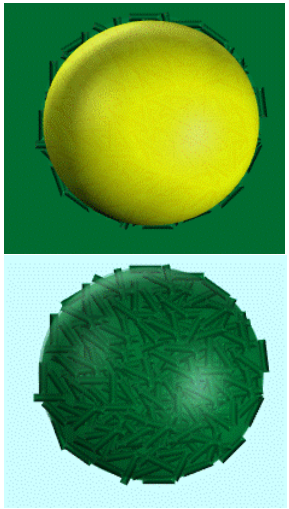
O/W stabilized with cellulose whiskers

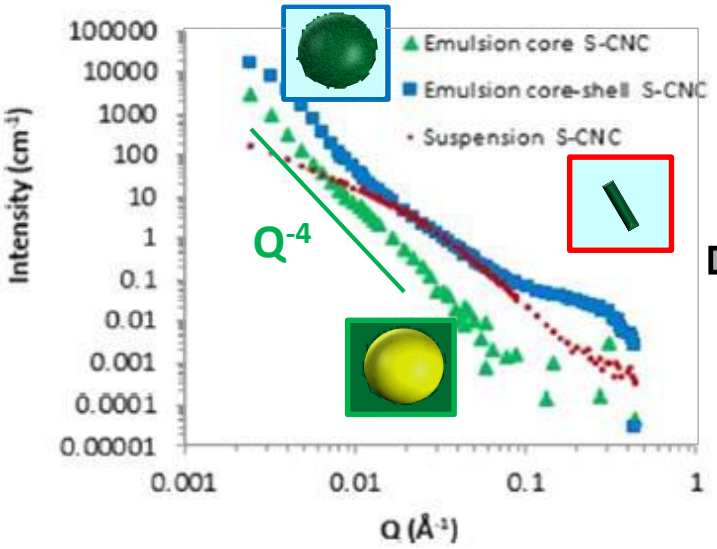




thickness :

Stabilization by a monolayer of cellulose whiskers





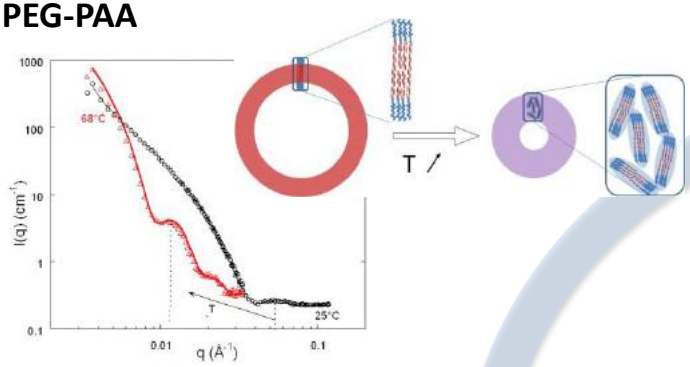
The cellulose whiskers are located in the water phase

Cherhal et al, Biomacromolecules, 2016

Stimuli responsive polymersomes

Thermosensitive Liquid Crystal Polymersomes

PEG-PAA



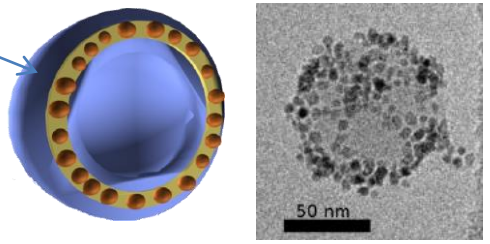
Stable thick capsule
-> Slow release

Soft matter (2011)

Magnetic polymersomes

PTMC-*b*-PGA

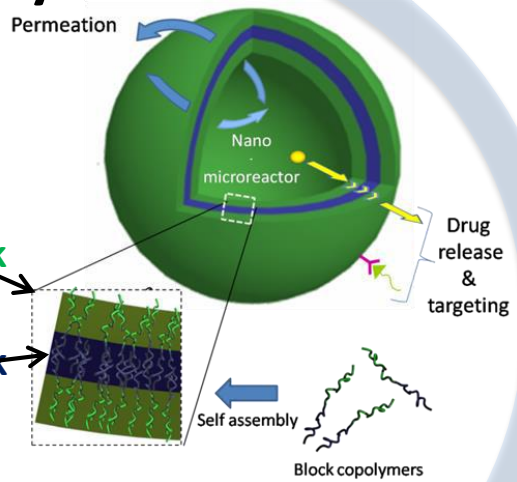
Fe_2O_3 nanoparticles



MRI, hyperthermia

ACS Nano 5, 1122 (2011)

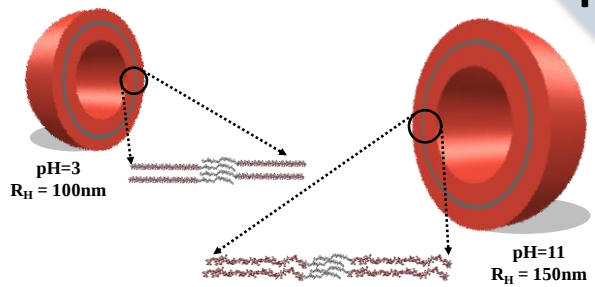
Polymersome



a versatile nanocarrier platfor
for therapeutic and diagnosis
applications

pH-responsive vesicles

Poly glutamic acid-*b*-PolyL-lysine

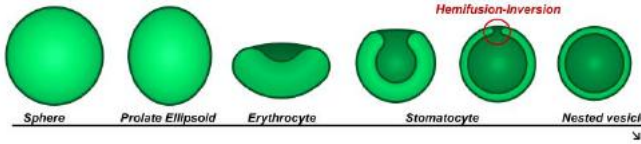


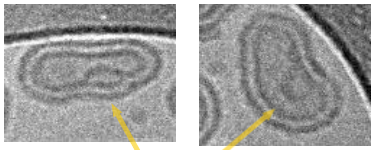
Size and conformation changes

Langmuir 21, 4308 (2005)
JACS 127, 2026 (2005)

Osmotic shocks Glucose/Water

PDMS-b-PEG





Budding

Nested vesicle
Vesicles processing

ACS Nano 7 (2013)

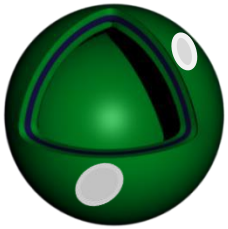
Stimuli responsive polymersomes

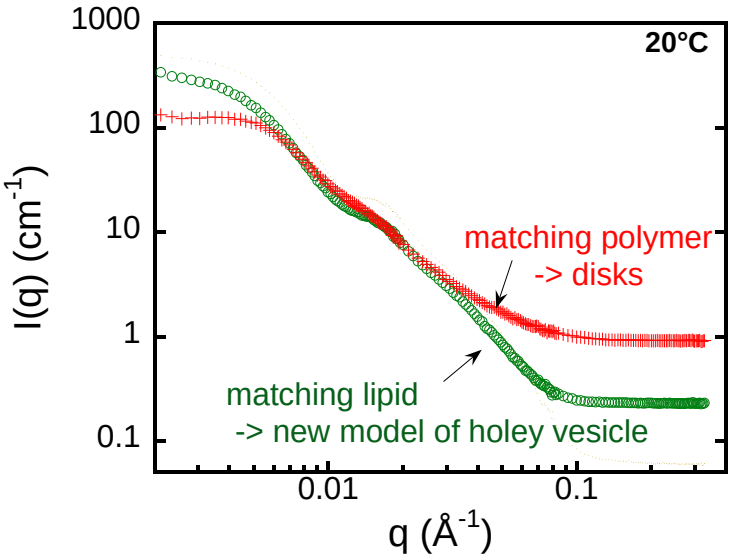
Hybrid (lipid/polymer) vesicles

PDMS-b-PEG / DPPC

Matching polymer
(« see » lipid phase)

Matching lipid
(« see » polymer phase)





Size of lipid nanodomains within vesicle membrane

Compartmentalized polymersomes

ACS Macro Letter (2015)
Macromolecules (2017)

Studies of stimuli responsive polymersomes: SANS problems

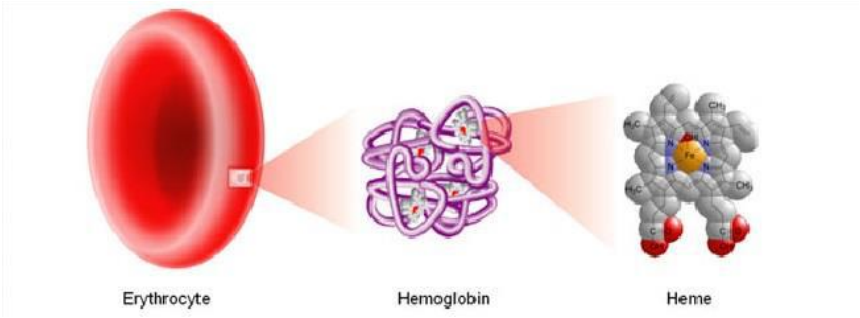
Collaborations:

- Laboratoire de Chimie des Polymères Organiques, Bordeaux
- Institut Curie, Paris
- CEA/NIMBE/LIONS, Saclay

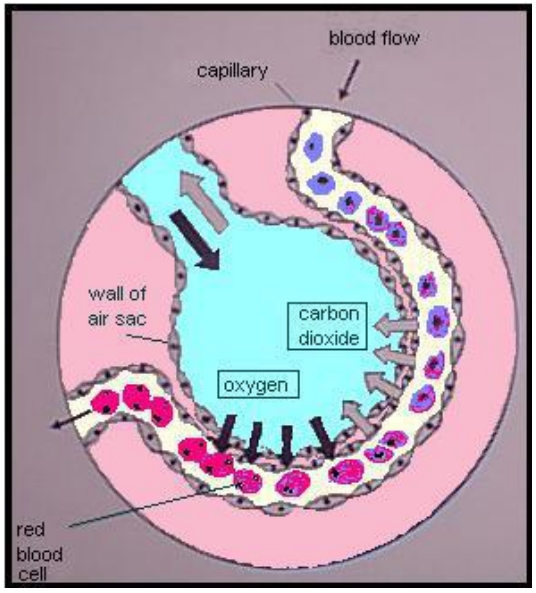
…

LCPO Laboratoire de Chimie des Polymères Organiques

Can hemoglobin diffusion in red blood cells improve oxygen capture ?



Red blood cells physiological role: transport of gaz (O_2, CO_2, NO …)

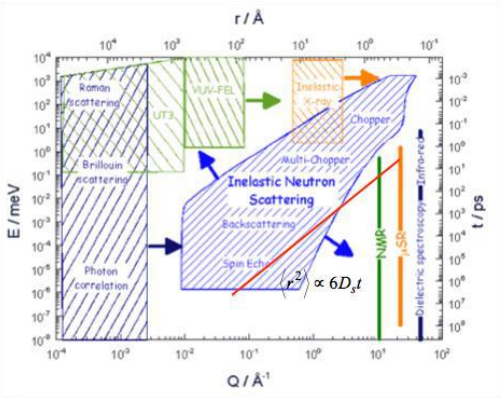


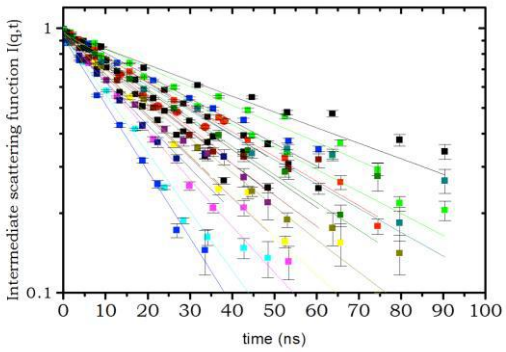
The resident time τ_r vary from 0.2 to 0.7 sec depending on the activity

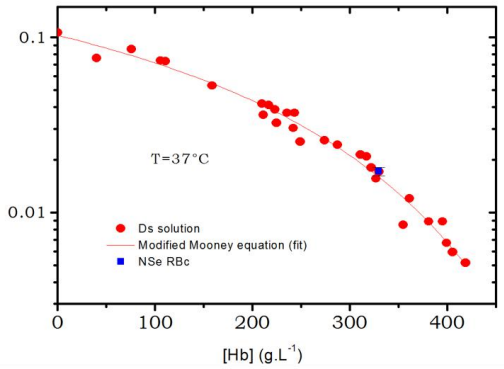
Hemoglobin must diffuse to the surface to capture oxygene (diffusion time ~0.1 sec)

Diffusion of the Hb as function of the concentration?

Can hemoglobin diffusion in red blood cells improve oxygen capture ?

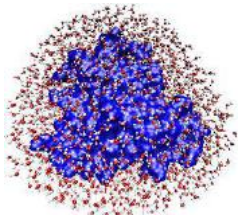


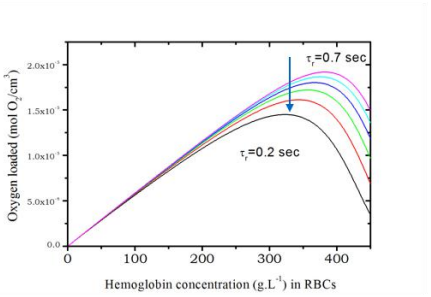




The diffusion of Hb is identical in solution and in the RBCs: Brownian type up to physiological concentration.

D_s measured by NSE





Physiological [Hb]=330mg.ml^{-1}

Model for oxygen capture without free parameter

Hemoglobin diffusion clearly helps to increase the quantity of O_2 captured (factor of 3)

The concentration of Hemoglobin in the RBCs corresponds to a maximum of oxygen transport for a human under strong physical activity

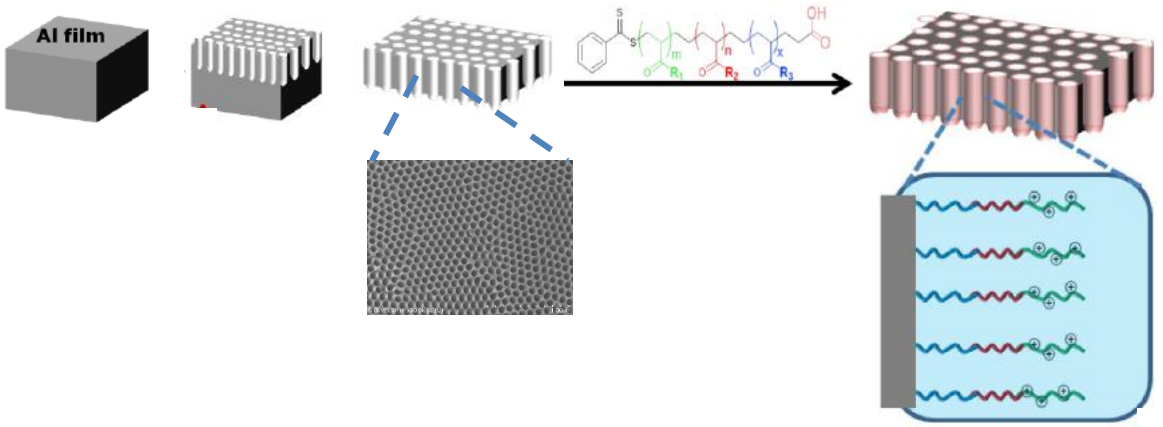
Multi-stimuli Responsive Polymer Functionalized Nanoporous Membrane

Synthesis of polymer grafted nanoporous alminum oxide membrane:

Various molecular architectures

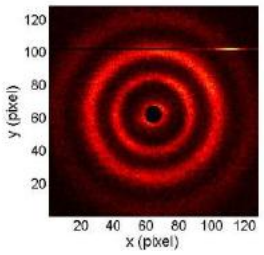
Multi-responsive copolymers for encoded functions:

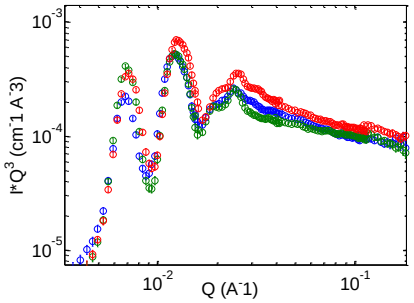
Charge / size selectivity

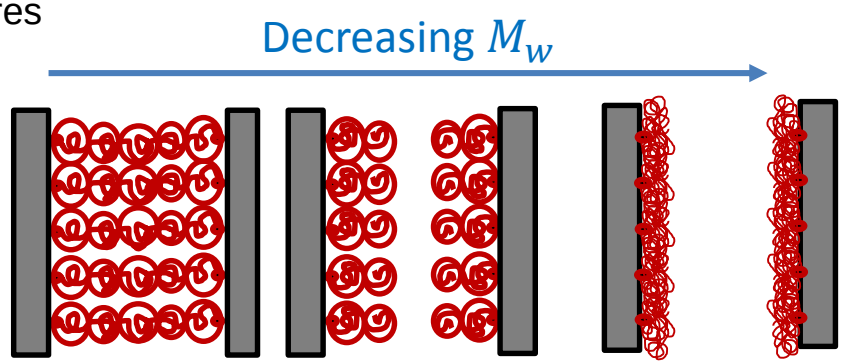


Small angle neutron scattering characterization:

Probing molecular conformation inside the nanopores



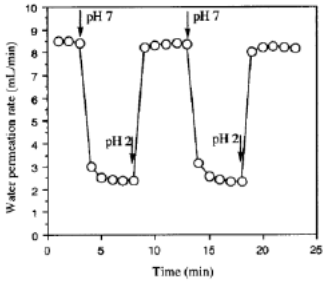




Multi-stimuli Responsive Polymer Functionalized Nanoporous Membrane

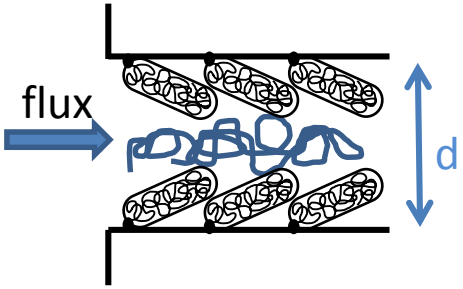
Toward smart nanopores:

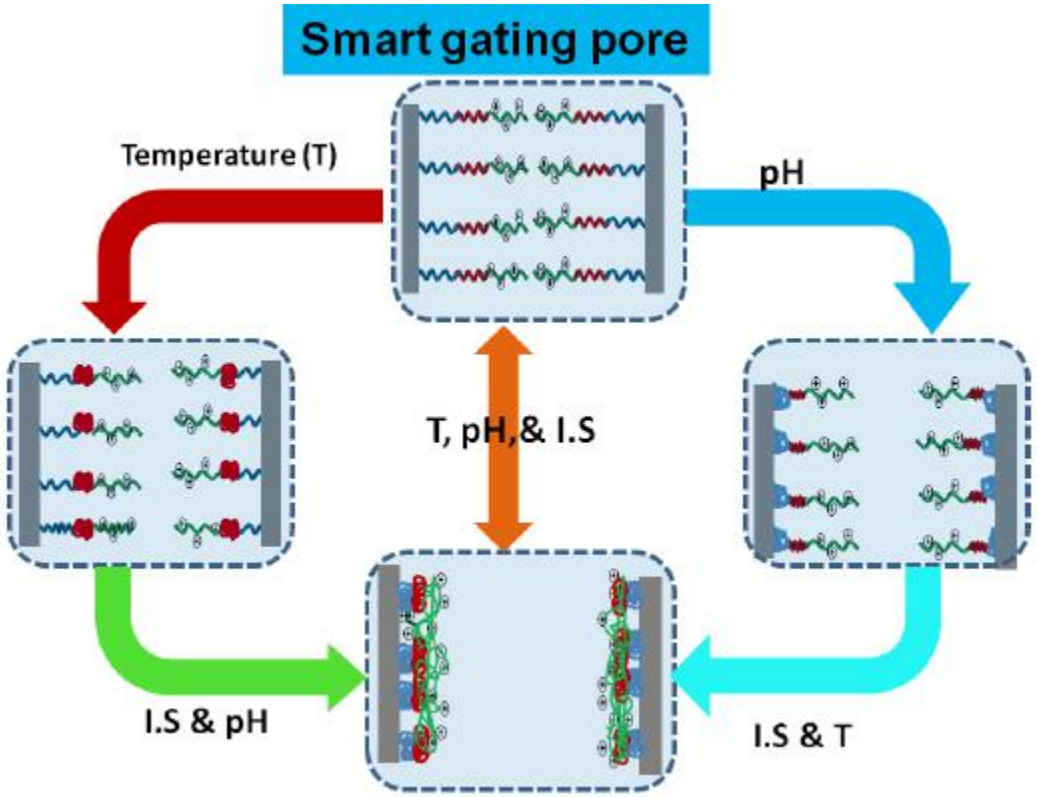
From molecular organization to permeation properties



Y. Ito et al ., *Polym. adv. tech.*, (2000)

Molecular conformation under flow





Application to protein filtration

Mimic protein exchange in cells

Prepared with:

Annie Brûlet
Fabrice Cousin
Stéphane Longeville
Alexis Chennevière