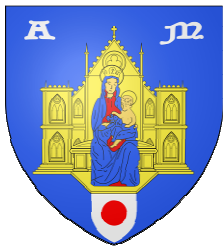




Magnetic ionogels for fluid handling in microfluidic devices

Bartosz Ziółkowski



Outline

- 1. The need for stimuli responsive materials**
- 2. Ionogels as scaffolds for stimulus responsive materials**
- 3. Magnetic ionogels**
- 4. Future work**
- 5. Conclusions**



1. The need for stimuli responsive materials

EU water

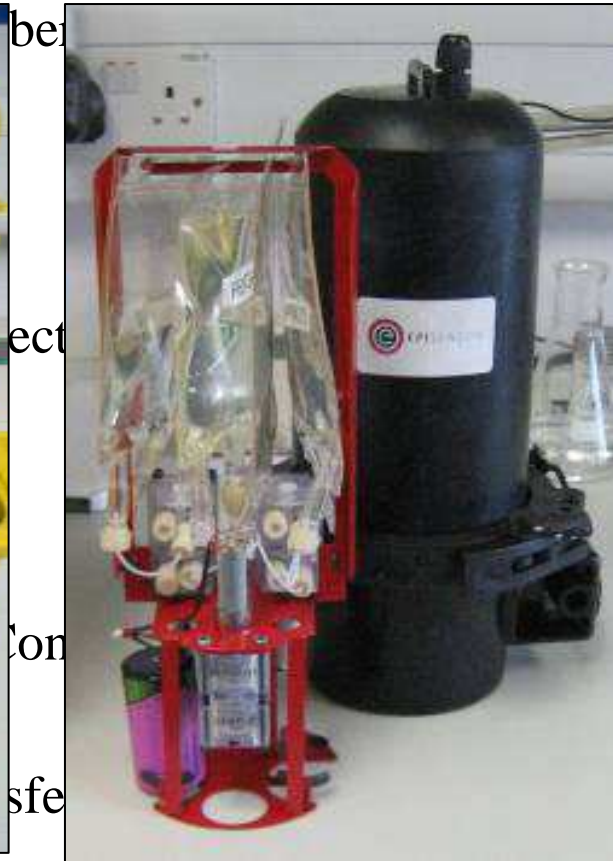
- Water B

- Environ

- Ground

- Integrat

- Europe



Hazardous substances in Europe's fresh and marine waters — An overview
EEA (European Environment Agency) Technical report No 8/2011



1. The need for stimuli responsive materials

ATWARM

(Advanced Technologies for **W**ater **R**esource **M**anagement)

Project 3.7

Next generation autonomous analytical platforms for remote
environmental monitoring:

Microfluidic platforms incorporating stimulus responsive materials
for water quality



1. The need for stimuli responsive materials

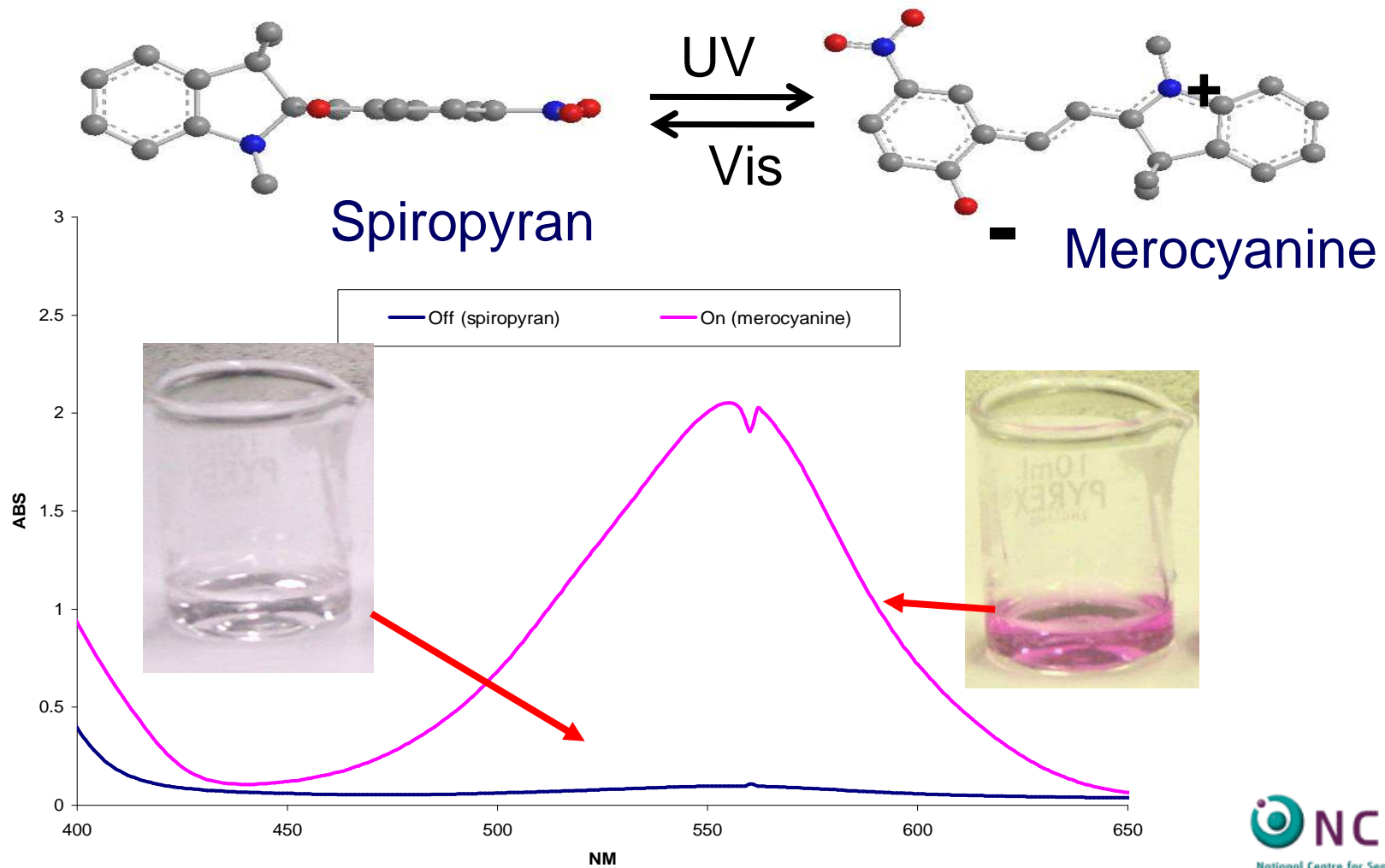
Stimuli responsive materials

- Materials that change their properties (shape, volume, colour, stiffness, conductivity etc.)
- Stimuli includes:
 - Light
 - Electric current
 - Heat
 - Magnetic field
 - Presence of certain chemicals
- Potential for use as valves and pumps in analytical fluidic chips



1. The need for stimuli responsive materials

Stimulus responsive materials



1. The need for stimuli responsive materials

Concept of ionogel

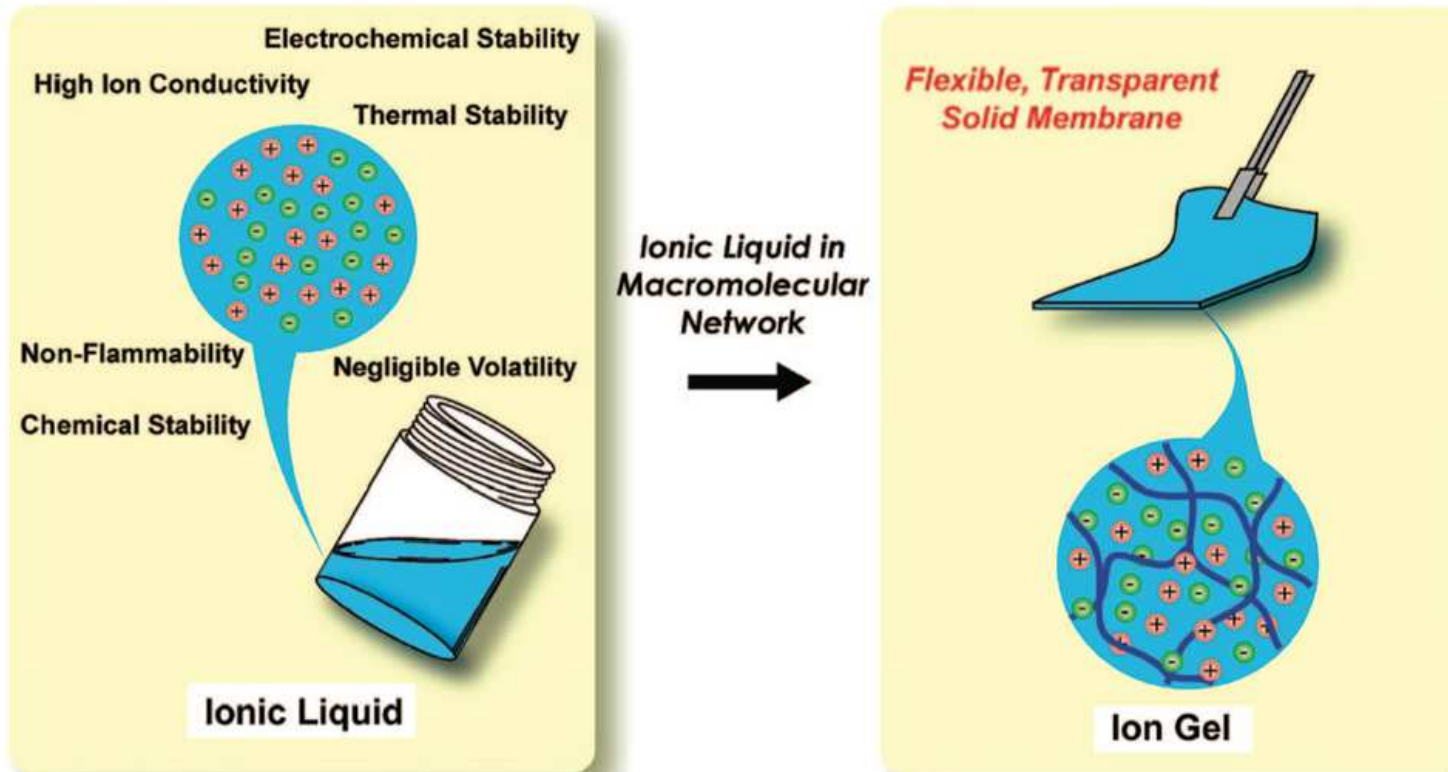
Ionogel

Inorganic

- Applications

Organic

- Applications in microfluidics



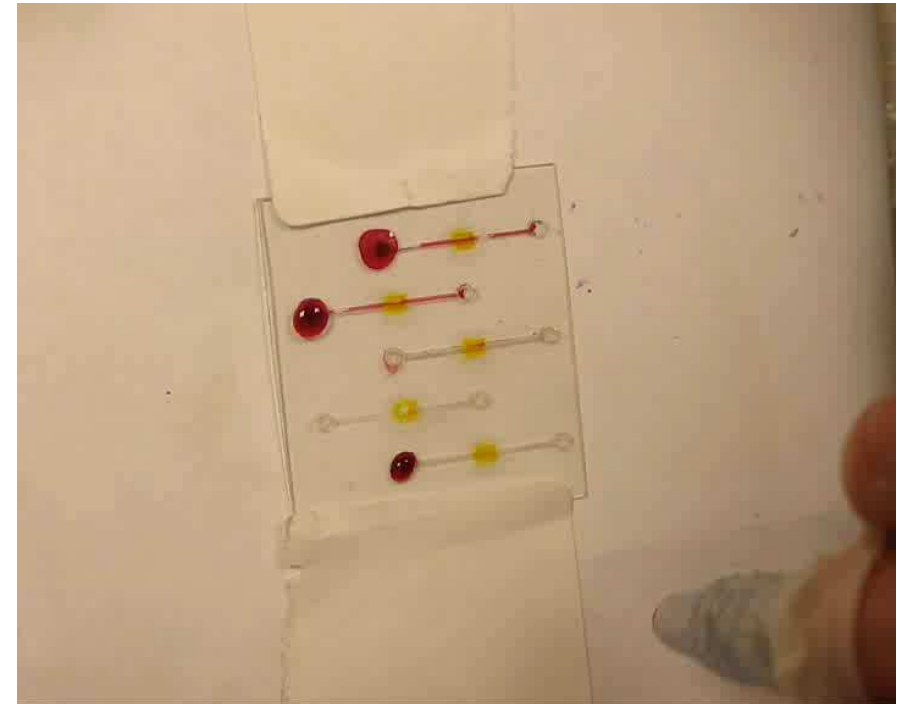
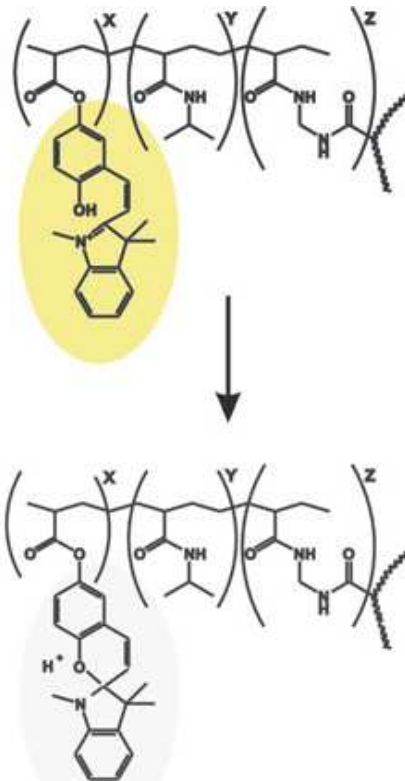
[1] M.-A. Nouze, J. L. Bideau, P. Gaveau, S. Bellayer and A. Vioux, *Chem. Mater.*, 2006, **18**, 3931-3936.

[2] T. Ueki and M. Watanabe, *Macromolecules*, 2008, **41**, 3739-3749.



1. The need for stimuli responsive materials

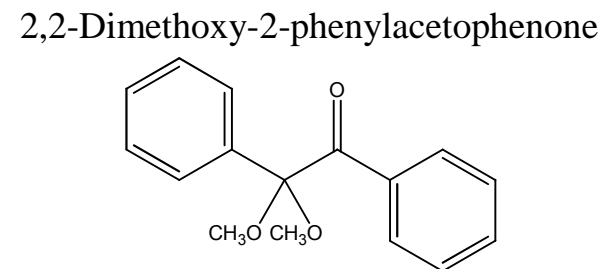
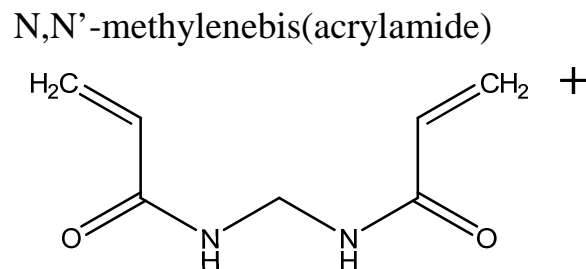
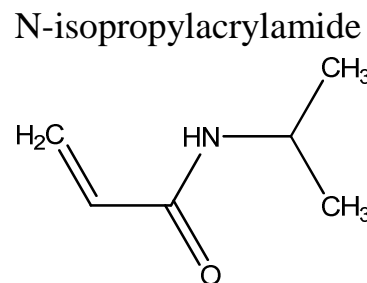
The combination of ionogels & stimuli responsive materials



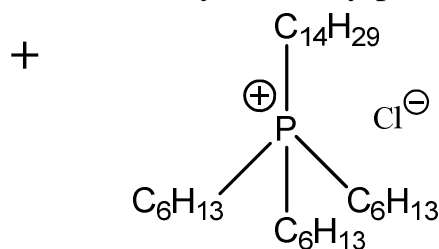
Benito-Lopez, F. *et al.* Lab on a Chip 2010, 10, 195.



2. Ionogels as scaffolds for stimulus responsive materials

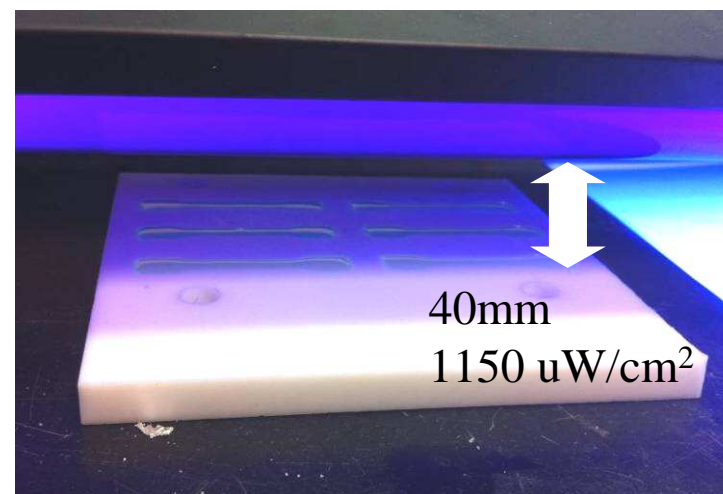
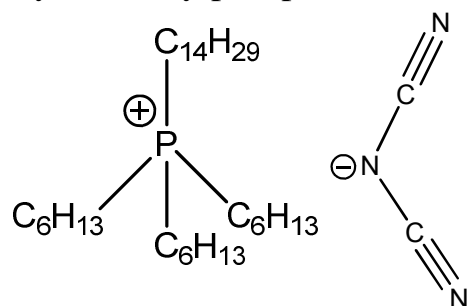


Trihexyltetradecylphosphonium chloride [P_{6,6,6,14}][Cl]

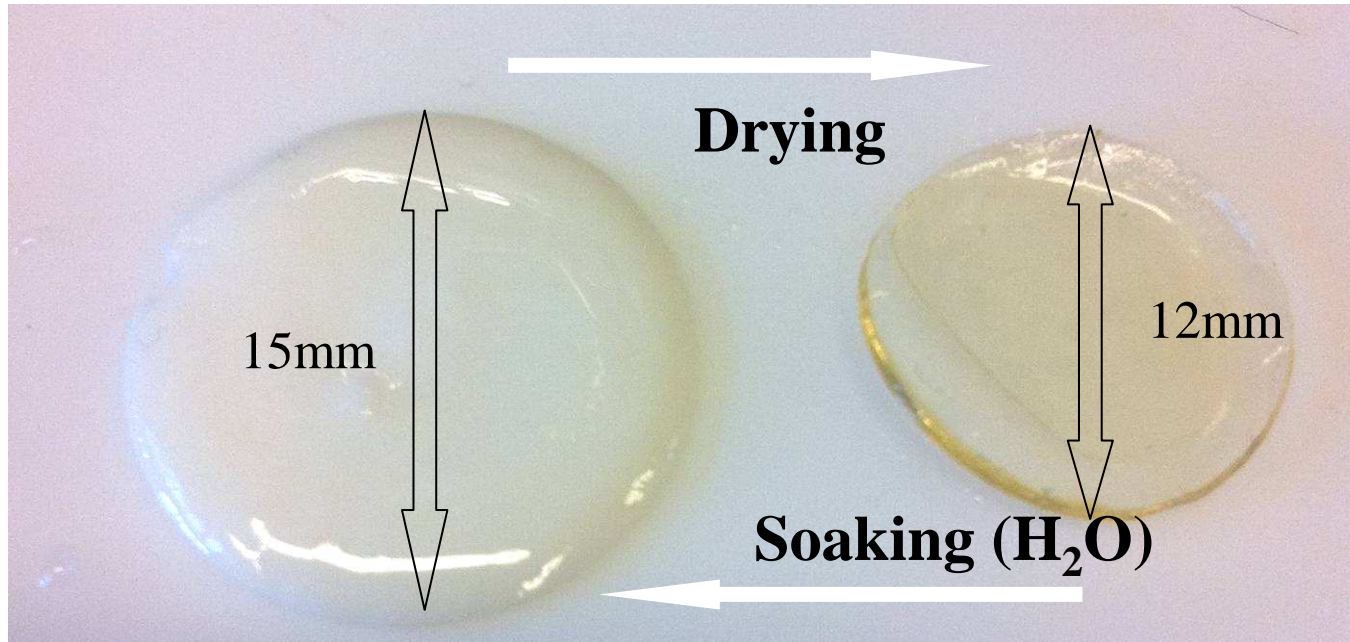


OR

Trihexyltetradecylphosphonium dicyanamide [P_{6,6,6,14}][DCA]



2. Ionogels as scaffolds for stimulus responsive materials



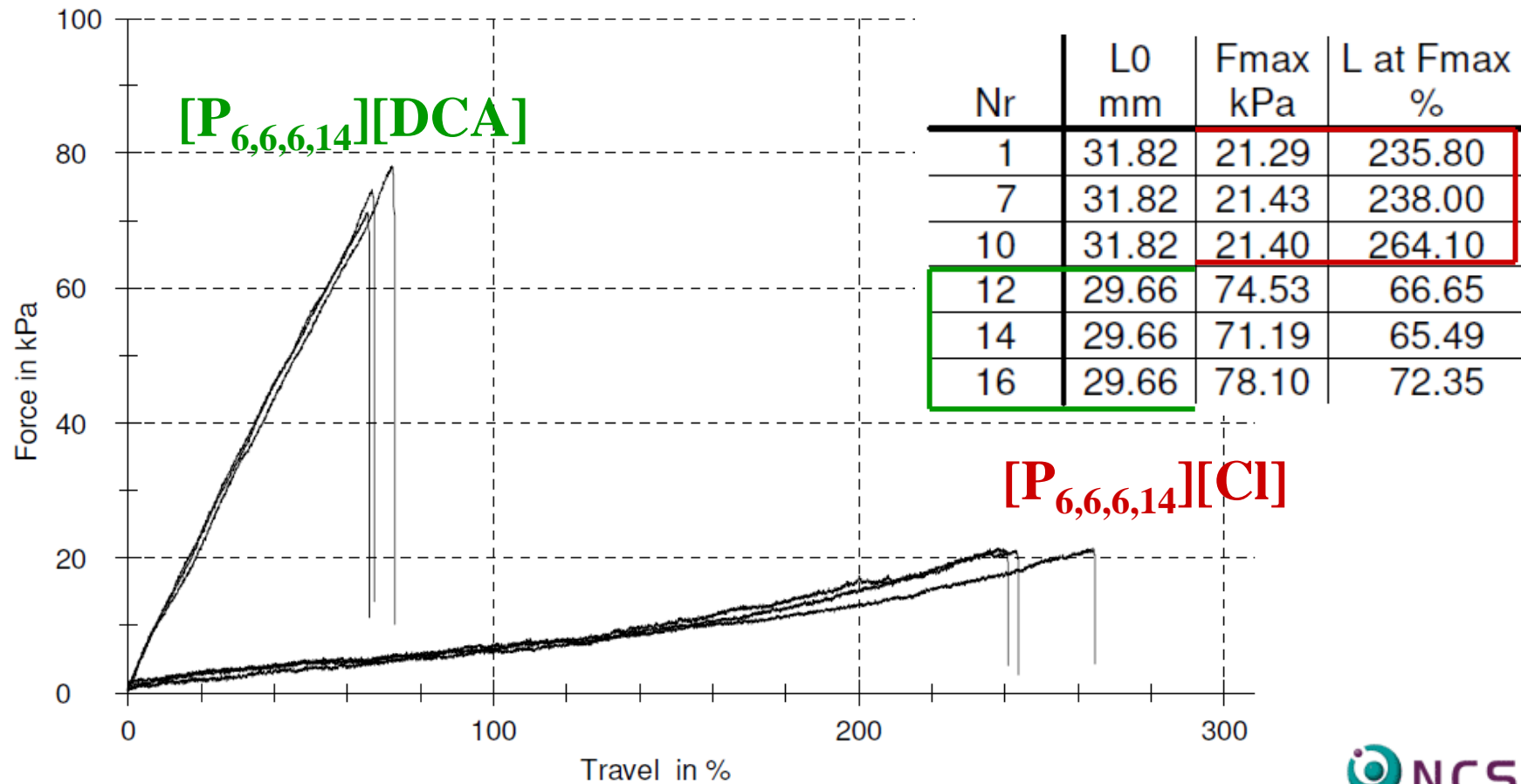
[P_{6,6,6,14}][DCA] - pNIPAM ionogels:

- *Do not dry out completely – remain flexible*
- *Do not leach in water – hydrophobic IL contained*
- *Retain pNIPAM's LCST properties*



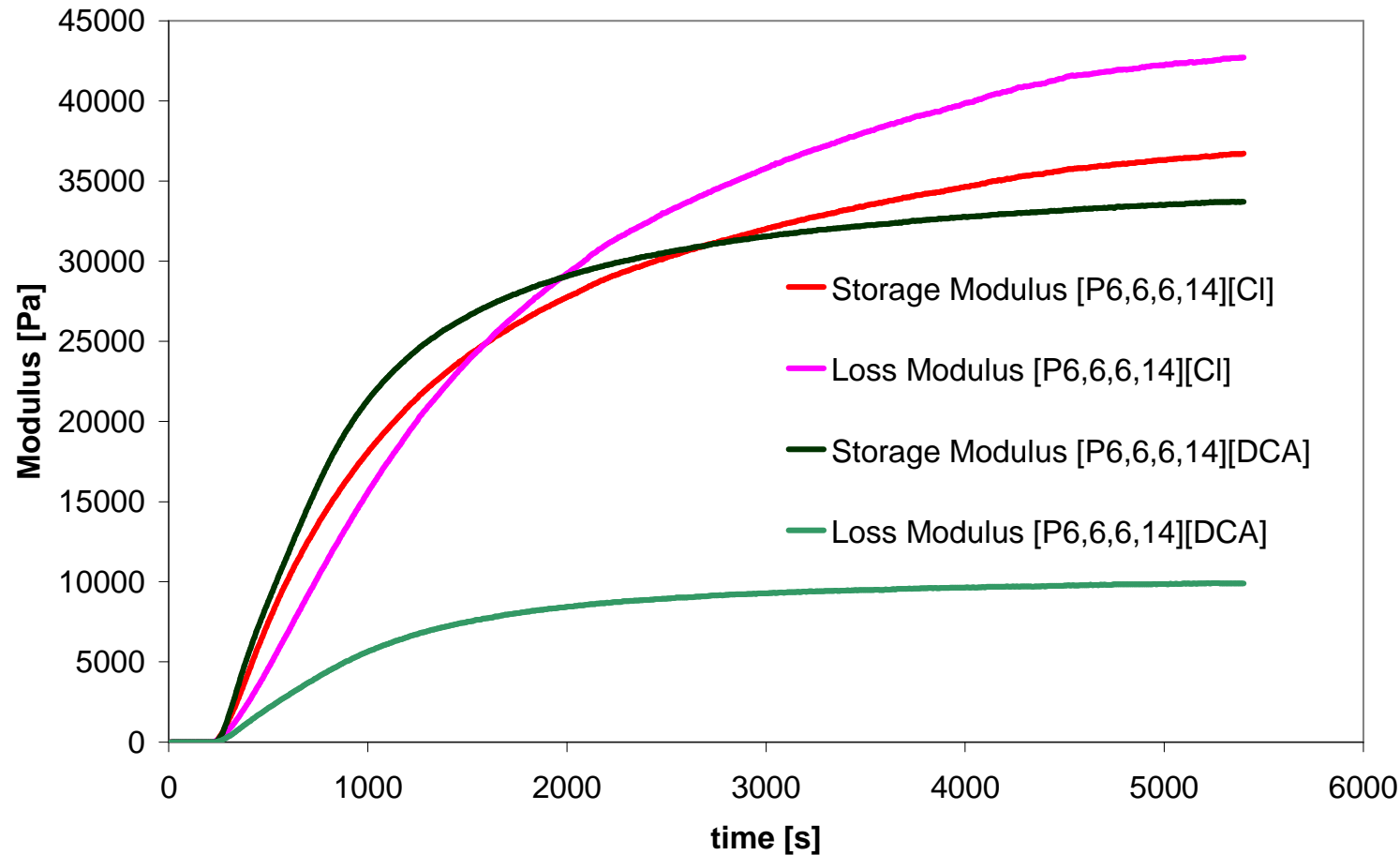
2. Ionogels as scaffolds for stimulus responsive materials

Tuning the flexibility of ionogels with IL anions



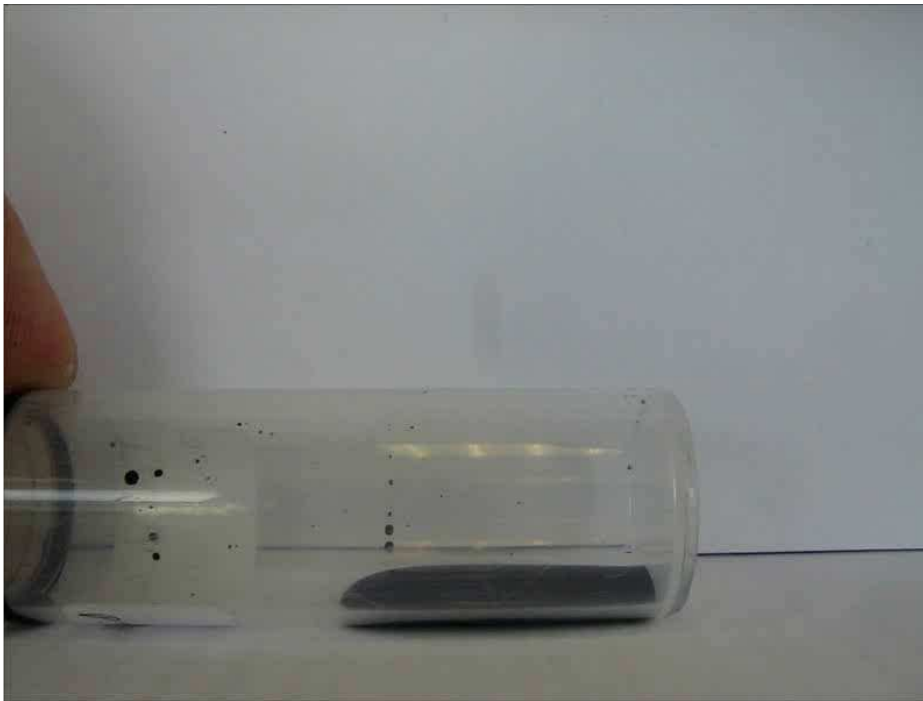
2. Ionogels as scaffolds for stimulus responsive materials

Curing characteristics of ionogels with different IL anions



3. Magnetic ionogels:

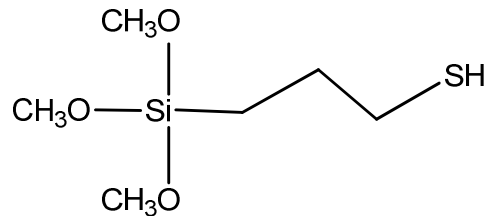
Another non-invasive stimulus Magnetic field



3. Magnetic ionogels:

Linking the inorganic Fe_3O_4 with the ionogel network

(3-mercaptopropyl)trimethoxysilane



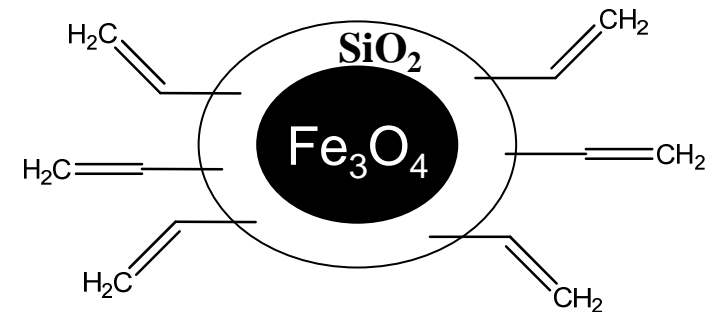
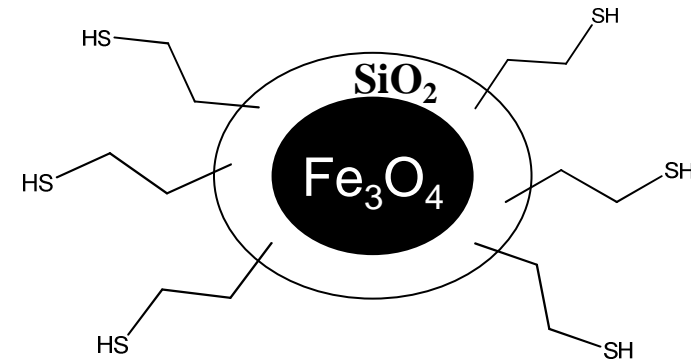
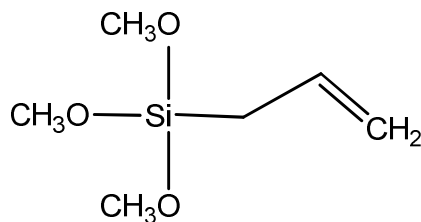
OR

+



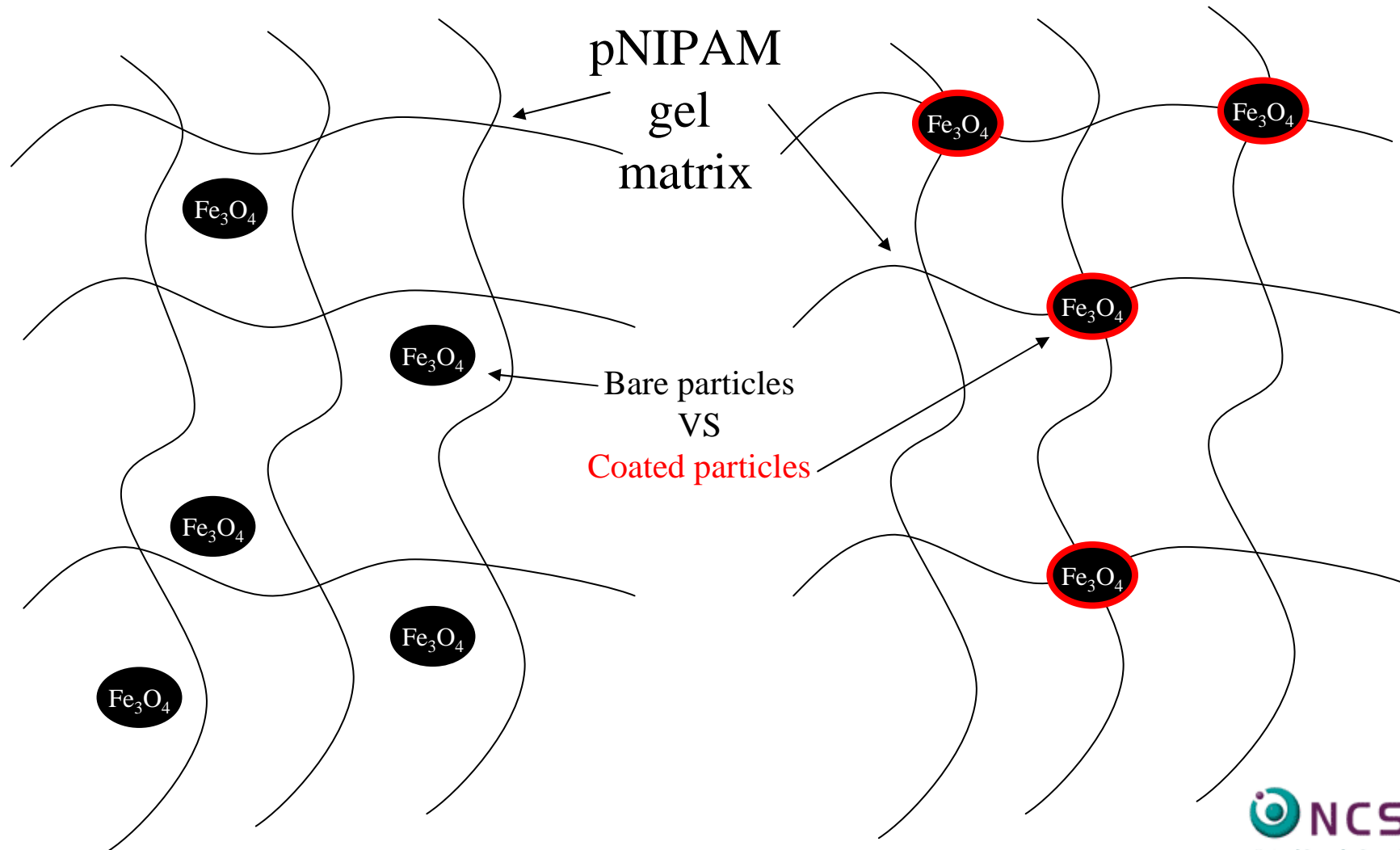
OR

Allyltrimethoxysilane



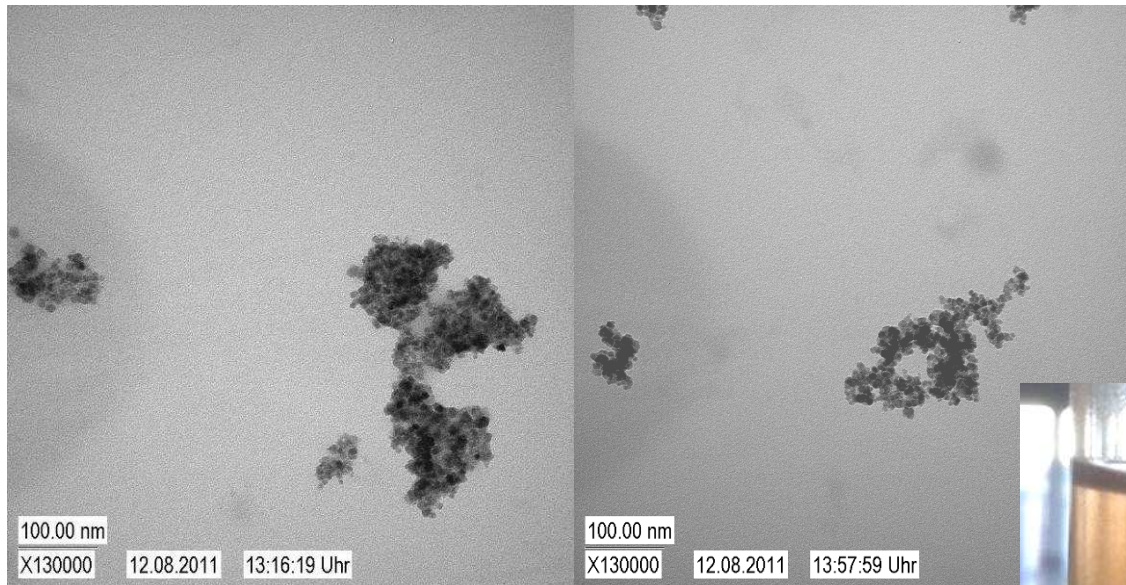
3. Magnetic ionogels:

Linking the inorganic Fe_3O_4 with the ionogel network



3. Magnetic ionogels: Preliminary results – the particles

*TEM picture of the magnetic nanoparticles coated with
MPTMS (left) & ATMS (right)*



*Left: bare Fe₃O₄ in acetone
Right: MPTMS coated Fe₃O₄ in acetone*



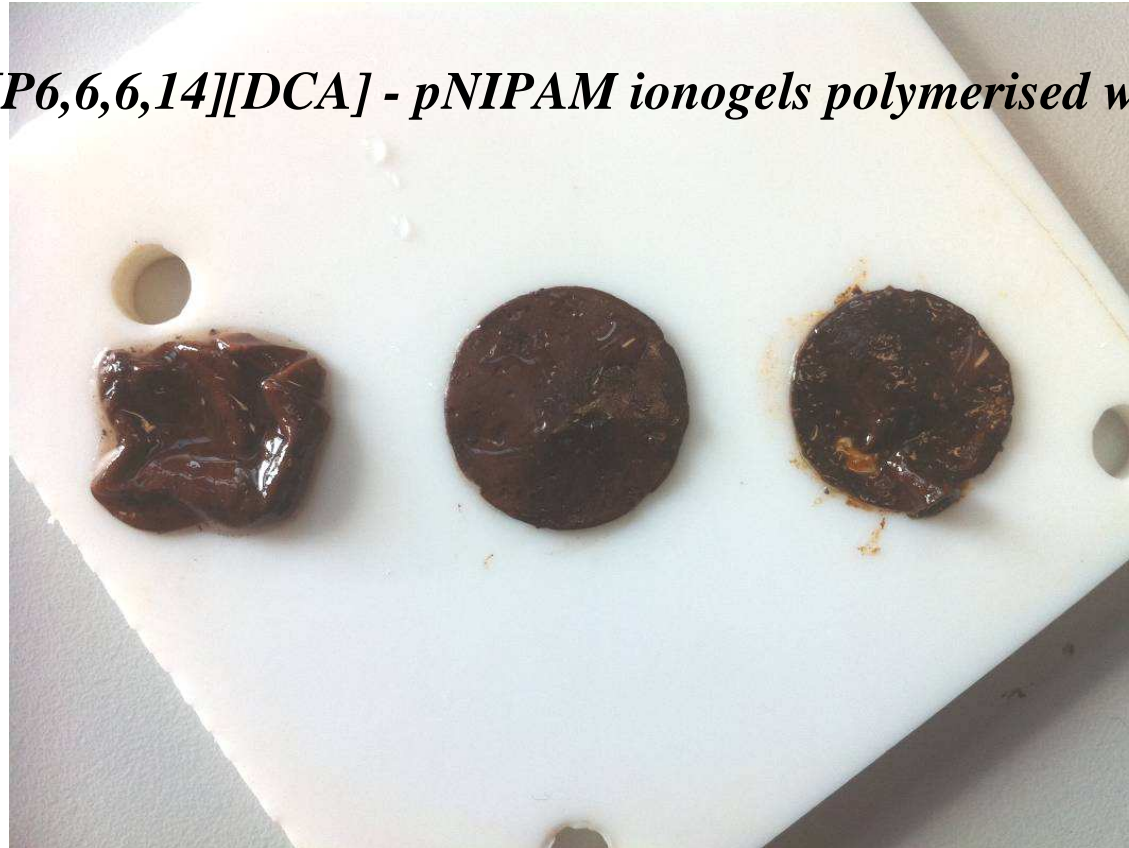
*Table 1. Dynamic light scattering analysis of
functionalised nanoparticles. Their sizes and size
distributions.*

	MPTMS@Fe ₃ O ₄	ATMS@Fe ₃ O ₄
DLS intensity peak [nm]	261	172
PDI [nm]	108	70



3. Magnetic ionogels: Preliminary results – Ionogels

[P6,6,6,14][DCA] - pNIPAM ionogels polymerised with:



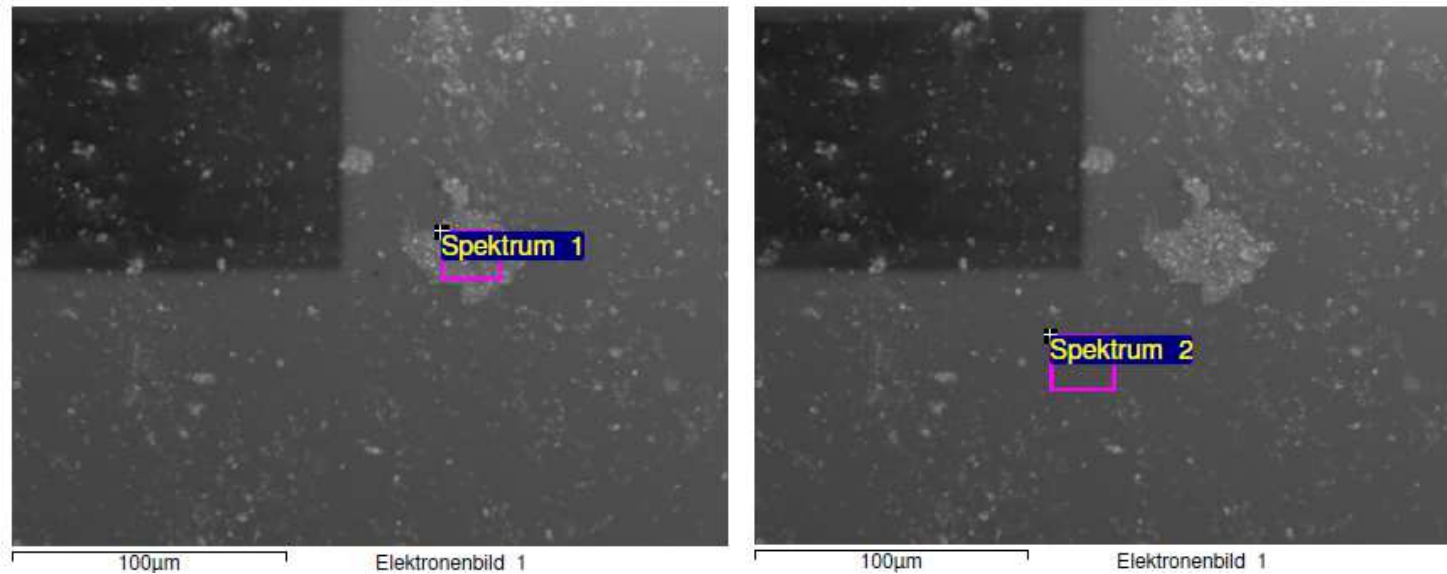
Left: bare Fe_3O_4 Middle: MPTMS coated Fe_3O_4 Right: ATMS coated Fe_3O_4

(20%wt in all)



3. Magnetic ionogels:

EDX analysis



[P_{6,6,6,14}][DCA] - pNIPAM ionogel polymerised with bare Fe₃O₄

Left: 25%Fe, 14%P

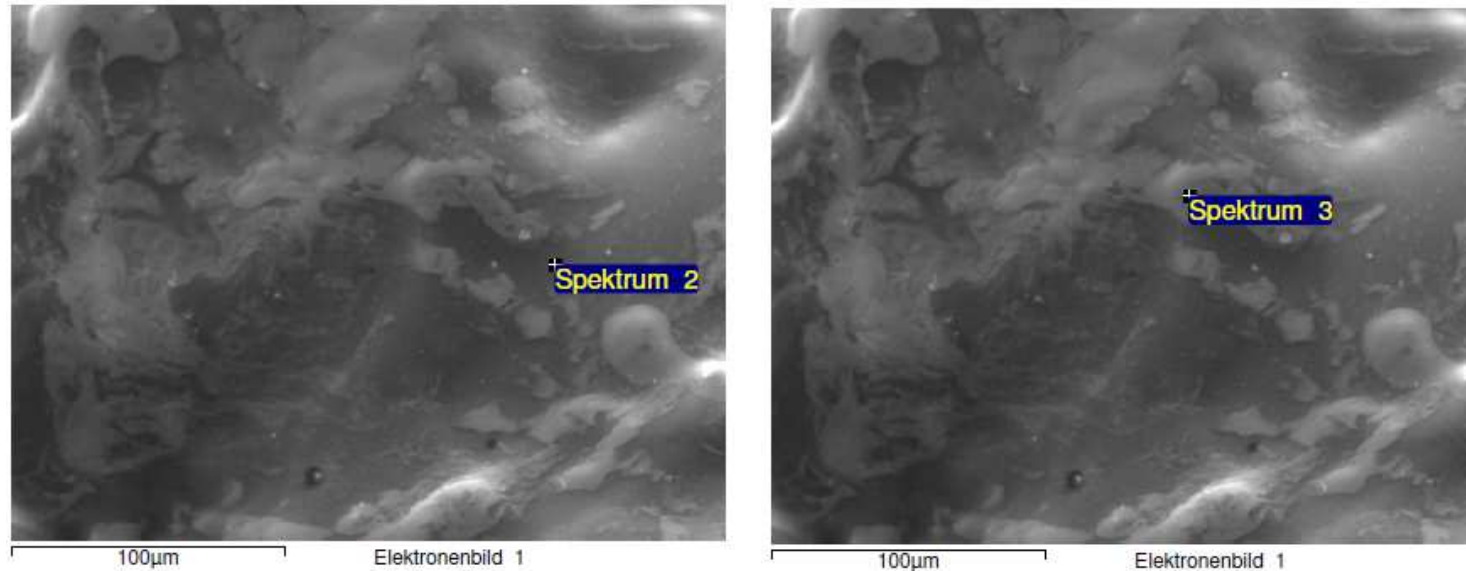
Right: 1%Fe, 27%P

Bare particles phase-separate in the final material



3. Magnetic ionogels:

EDX analysis



[P_{6,6,6,14}][DCA] - pNIPAM ionogel polymerised with ATMS coated Fe₃O₄

Left: 25%Fe, 14%P

Right: 36%Fe, 6%P

Coated particles do not phase separate



3. Magnetic ionogels:

Preliminary results – magnetic actuation of the polymer



National Centre for Sensor Research



4. Future work

- Optimisation of the organosilicon coating process of magnetite
- Mechanical analysis (rheometry) to determine the copolymerisation of particles
- Magnetic analysis of ionogels to determine their susceptibility to magnetic fields
- Integrating this composite material into microfluidic manifolds and demonstrating a working valve and a working pump



5. Conclusions

- ▶ Water resource management needs new technologies for water monitoring
- ▶ Smart - stimulus responsive materials can revolutionise sampling and analysis
- ▶ Ionogels – functional polymeric sponges filled with a non-volatile IL
- ▶ Photo-actuated ionogels can work as low-power microfluidic valves
- ▶ ILs impact the ionogel's curing and stiffness
- ▶ Magnetic field is another very attractive, non-invasive actuation method
- ▶ Magnetic nanoparticles can be coated with polymer linker organosilicon groups
 - ▶ Increased ionogel durability
 - ▶ Increased compatibility between the polymer and the particles
 - ▶ Reversible bending in non-uniform magnetic fields achieved



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