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Nanoparticules Polymériques Plurifonctionnelles: Applications comme Capteurs Fluorescents

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Chantal Larpent

Projet ANRCPM , PNano-2005

UVSQ
ILV
Eq. C. larpent

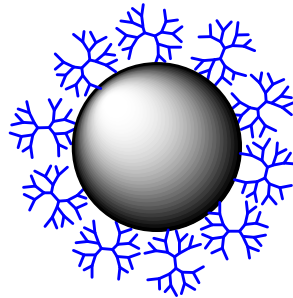
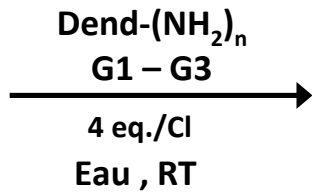
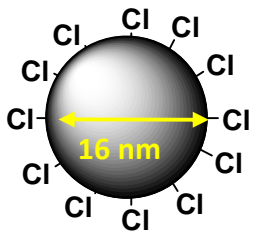
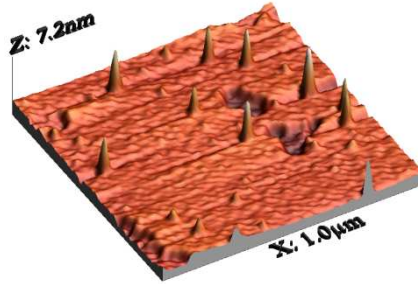
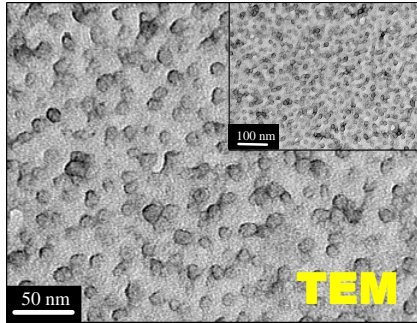
ENS-Cachan
PPSM
Eq. R. Pansu

ENS-Cachan
LPQM
Eq. J. Zyss, S. Brasselet

J3N, Toulouse, 21-23 Octobre 2009

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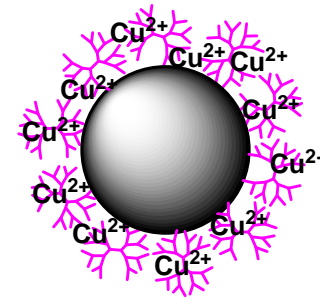
Exemples de Nanoparticules Plurifonctionnelles



270 G1/NP
↔ > 1000 NH₂
130 G3 / NP
↔ > 2100 NH₂

Cu²⁺

Eau

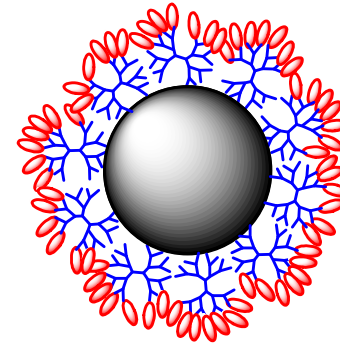


G3
~ 7.5Cu/Dend
↓
> 900 Cu / NP

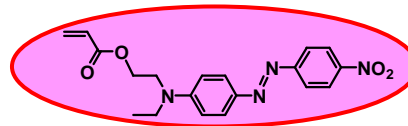
→ Matériaux hybrides
→ Capteurs

Chimie
"Clic"

Eau, RT



G3
↓
1250 Dyes/NP



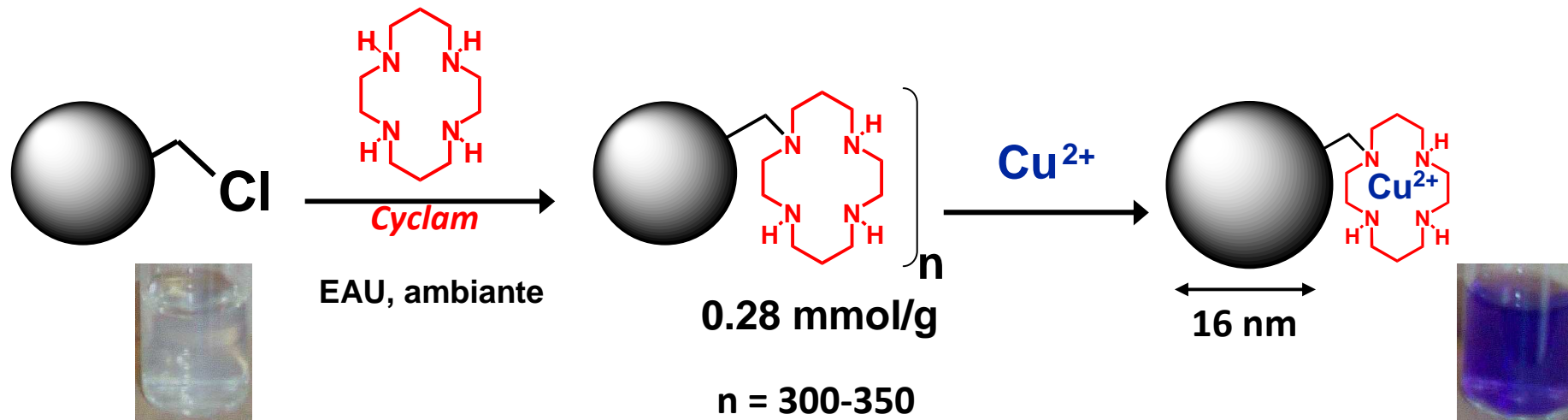
→ Nano-Matériaux Multifonctionnels (Multicouches)



Small, 2008, 4, 833.

J. Polym. Sci. A, 2008, 46, 3375.

Nanoparticules à propriétés de complexation spécifique

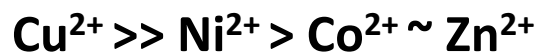


Complexation instantanée (~ 95%)

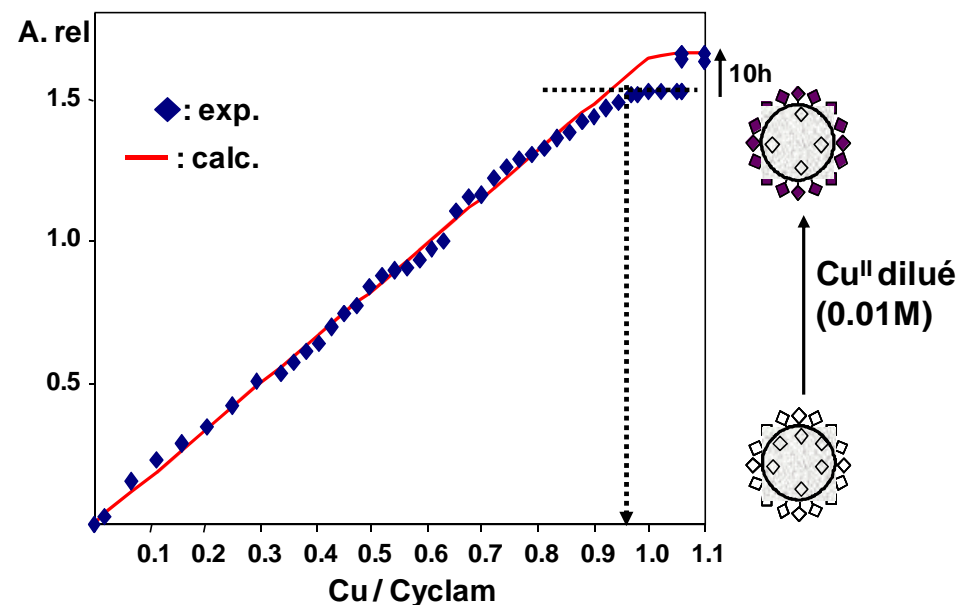
↳ Propriétés analogues à la solution

Cinétique et capacité de complexation

Sélectivité



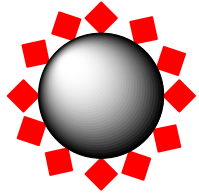
$K : 10^{27} \quad 10^{23} \quad 10^{20}$



Macromolecules, 2002, 35, 1644;
C. R. Chimie, 2003, 6, 1275.

Nanoparticules Fluorescentes

Encapsulation de fluorophores hydrophobes



(NP réticulée)

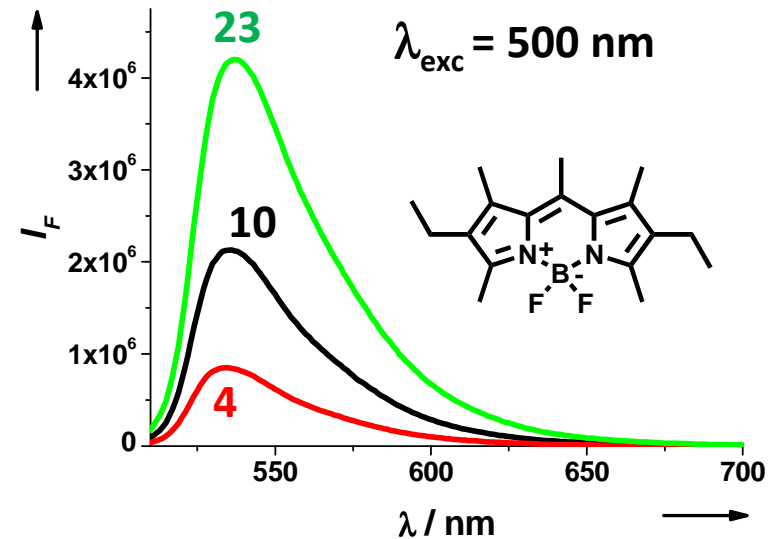
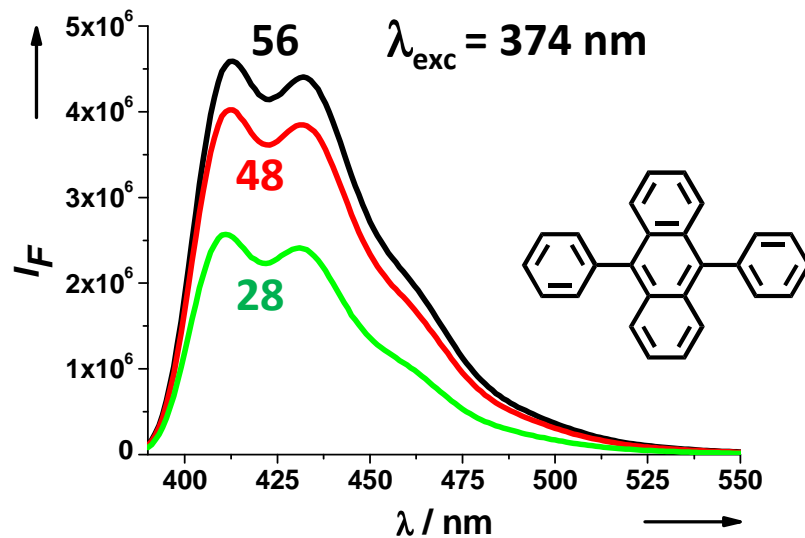
1) Gonflement \star solution dans CH_2Cl_2

2) Evaporation du solvant



1 \rightarrow \sim 75 /NP

\hookrightarrow Propriétés modulables : Nature du fluorophore
Taux de dopage



Applications : Nanocapteurs Fluorescents

2 approches

❑ Sonde fluorescente greffée en surface

Accessibilité

Ratiométrique : NP bifluorescente

❑ Nanocapteurs auto-assemblés

Association Fluorophore + Ligand

Détection par transfert d'énergie

NP = Template

Apport de la taille nanométrique

✓ Effets de confinement

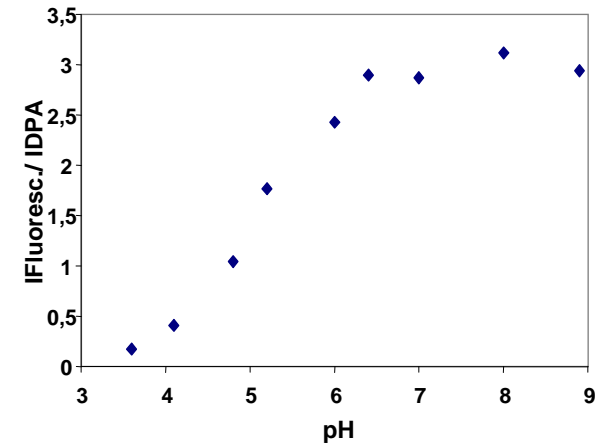
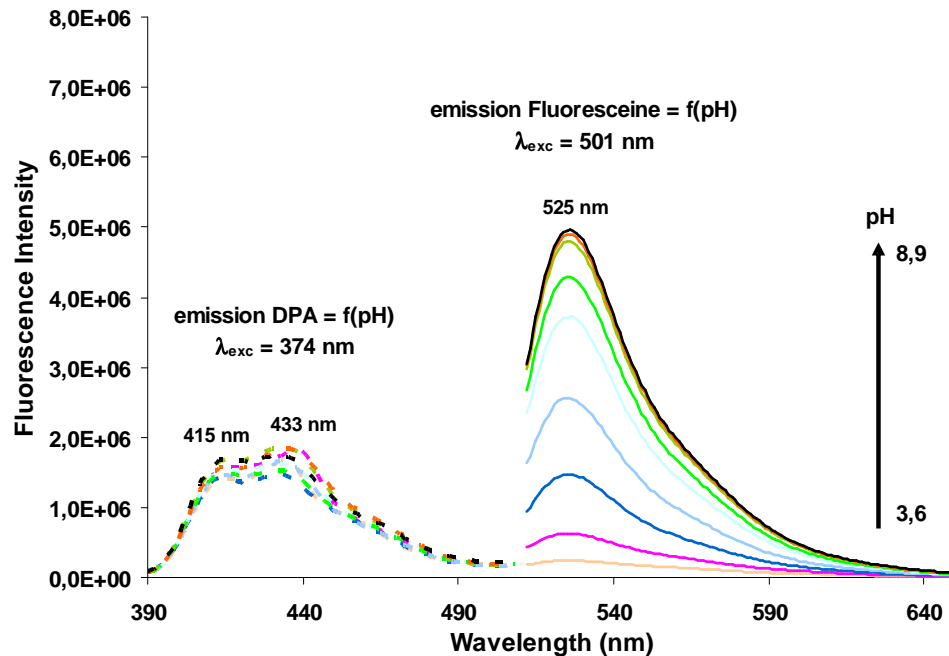
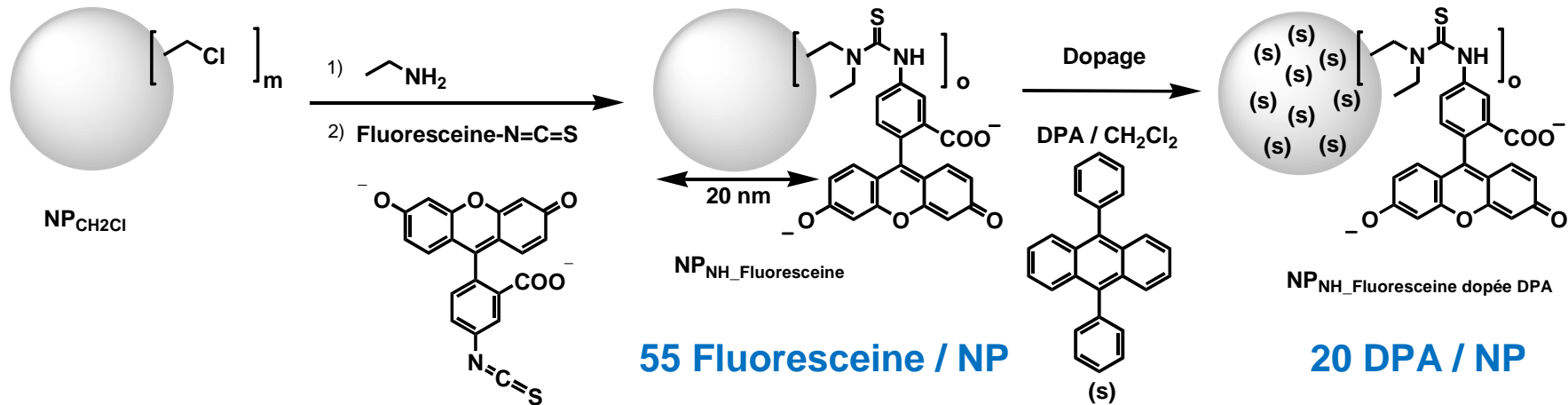
✓ Rapport Surface/Volume

↳ Accessibilité

Nanosondes de pH ratiométriques

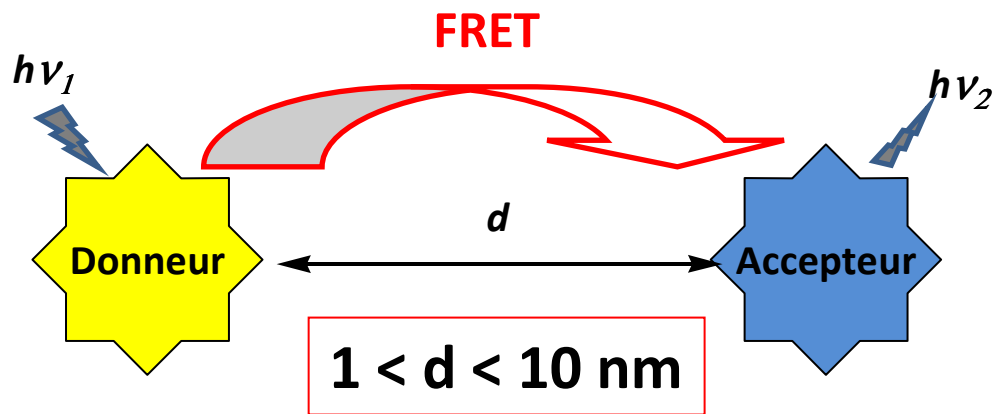
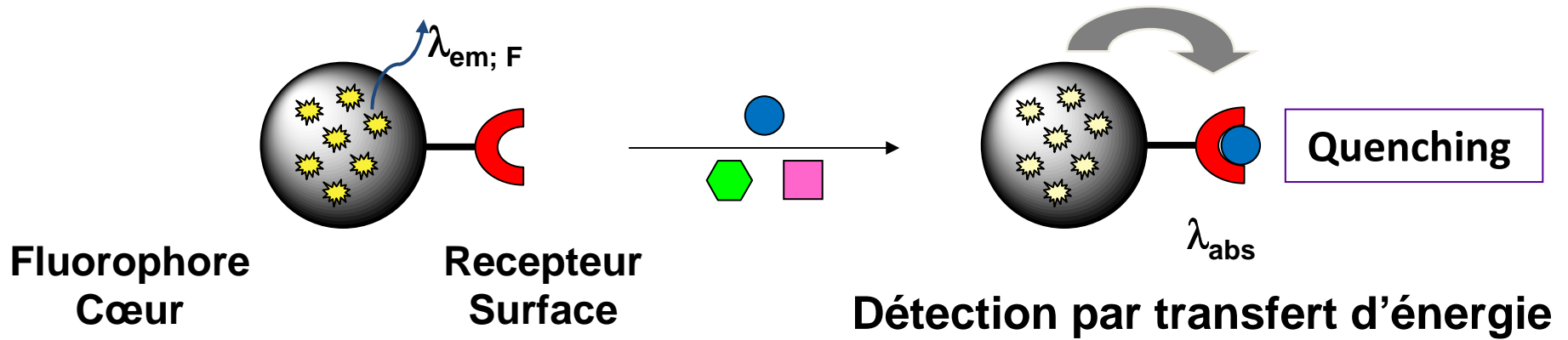
Sonde pH sensible: Surface

Référence : Coeur



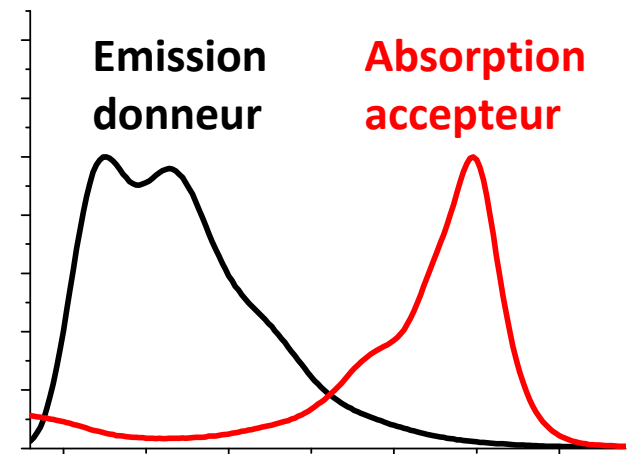
↔ Réversible , Réutilisable

Nanocapteurs Fluorescents Auto-assemblés



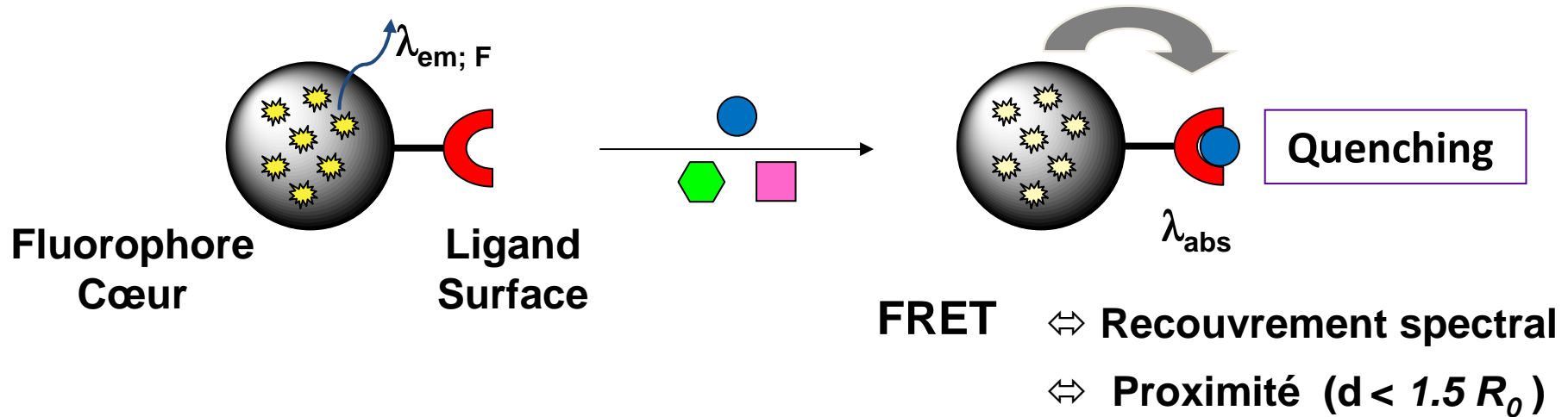
Efficacité du transfert d'énergie $E = \frac{R_0^6}{R_0^6 + d^6}$

Transfert $\Leftrightarrow d \leq 1,5 R_0$



Recouvrement spectral
 $\rightarrow R_0$ (E = 0,5)

Nanocapteurs Fluorescents Auto-assemblés

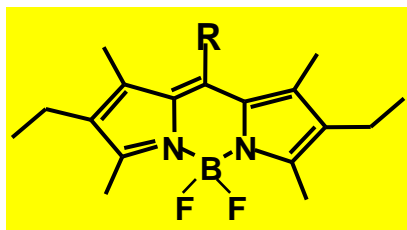
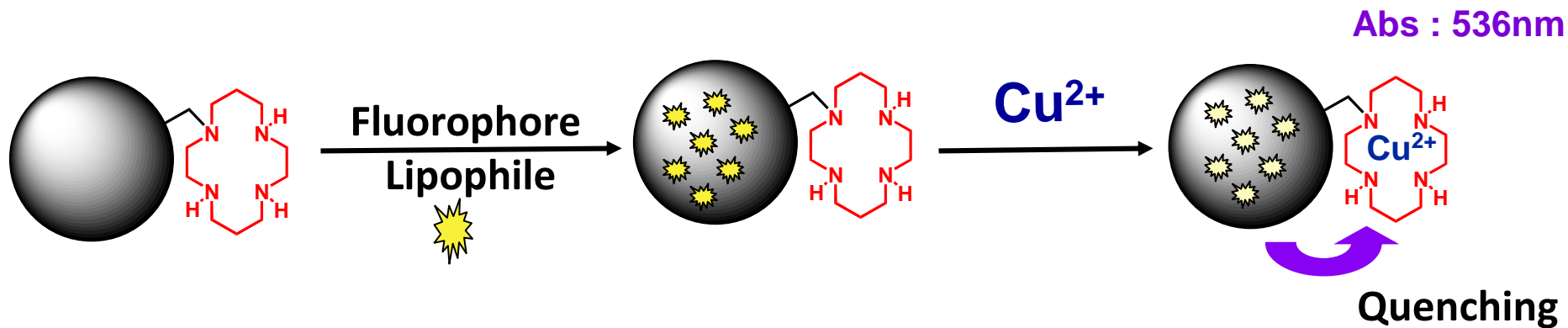


Nanoparticules { **Volume Restreint (Confinement)**
Rapport Surface / Volume élevé

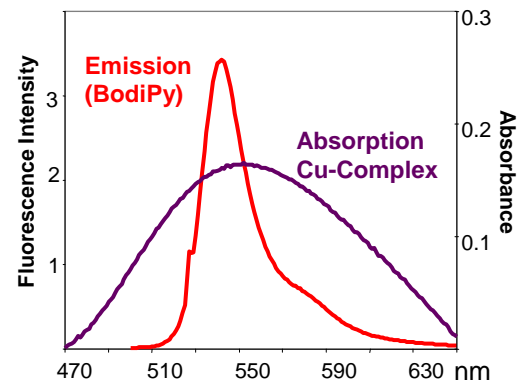
- ↪ Efficacité du Transfert (Proximité fluorophore / complex)
- ↪ Accessibilité du ligand
- ↪ Fluorophore protégé / milieu extérieur

Approche Modulable : Variation du fluorophore et/ou du ligand

Capteurs Fluorescents de Cations Métalliques (Cu^{2+})

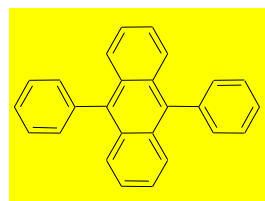


R = Me (PM 567)
R = Mesityle

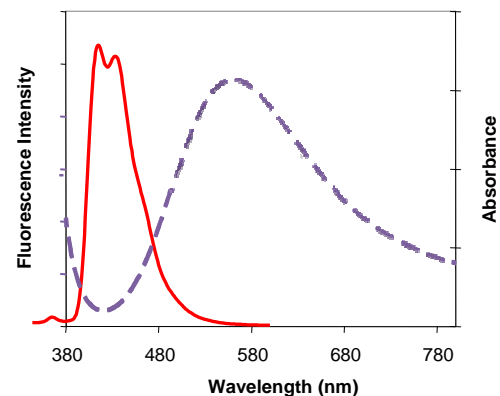


$R_0 = 2.2 \text{ nm}$

$d_c \sim 3.3 \text{ nm}$



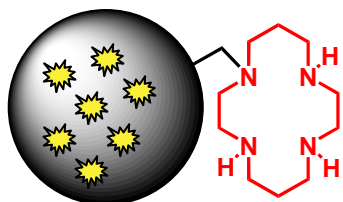
DPA



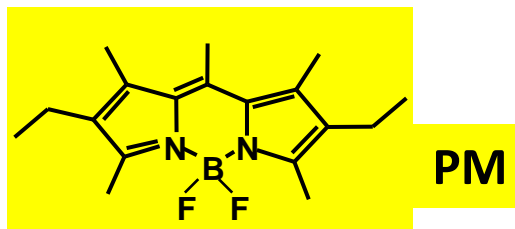
$R_0 = 1.5 \text{ nm}$

$d_c \sim 2.2 \text{ nm}$

Capteurs Fluorescents d'Ions Cuivriques (Cu^{2+})

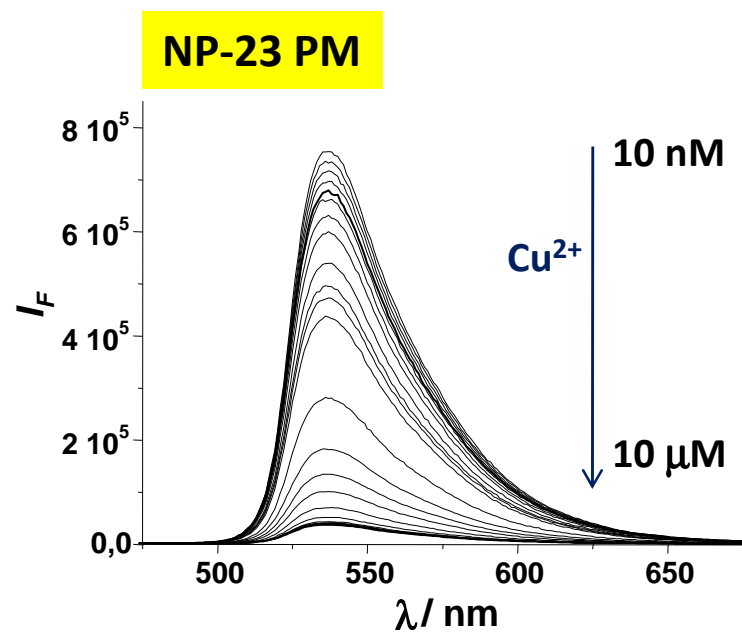


4 à 50 PM/ NP



$R_0 = 2.2 \text{ nm}$

$d_c = 3.2 \text{ nm}$



($\lambda_{\text{ex}} 536 \text{ nm}$)

30 mg NP/L ; 20 nM

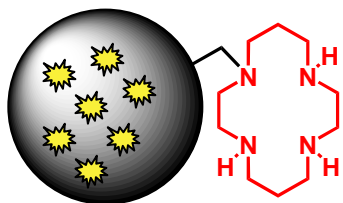
$\Rightarrow \sim 90 \%$ des sondes accessibles

Limite de détection: 20 nM

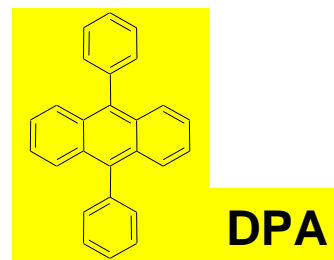
$\sim 1 \text{ Cu}^{2+}$ par particule

$K_{\text{sv}} = 1,86 \cdot 10^6 \text{ L/mol}$

Capteurs Fluorescents d'Ions Cuivriques (Cu^{2+})



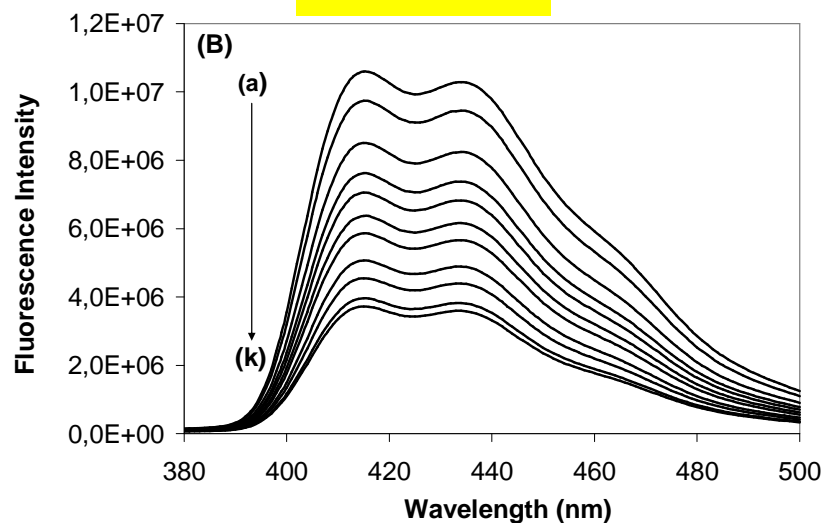
20 à 55 DPA / NP



$R_0 = 1.5 \text{ nm}$

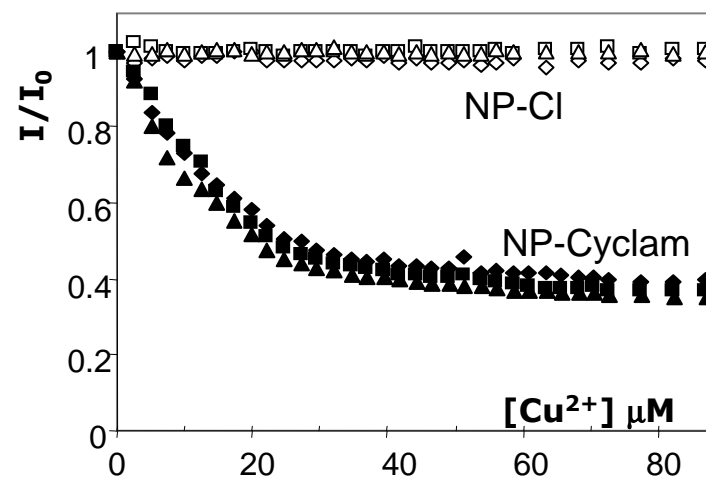
$d_c = 2.2 \text{ nm}$

NP-40 DPA



$(\lambda_{\text{ex}} 374 \text{ nm}) ; 30 \text{ mg NP/L}$

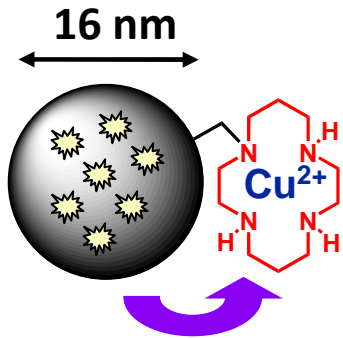
Limite de détection : $0.5 \mu\text{M}$



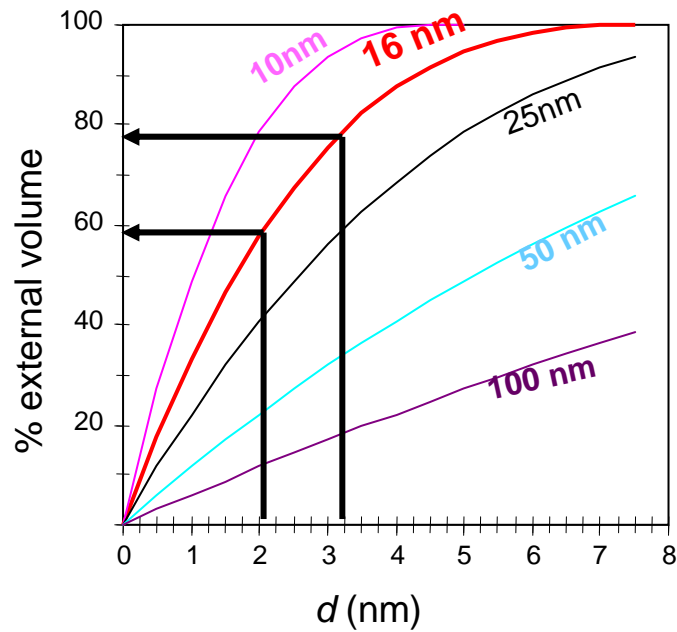
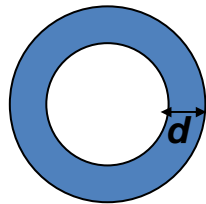
⇒ 60-70% de sondes accessibles

$K_{\text{sv}} = 2.10^5 \text{ L/mol}$

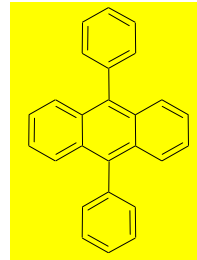
Efficacité du Transfert



Modèle
Core-Shell



DPA



$$K_{sv} = 2.10^5 \text{ L/mol}$$

DL : micromol/L

60% dye quenched

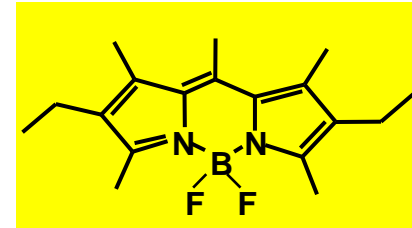
$$R_{o/CuL} = 1.5 \text{ nm}$$

$$d_c \sim 2.2 \text{ nm}$$

$$V_{\text{acces}} \sim 60 \% V_{NP}$$

Efficacité du quenching

PM



$$K_{sv} = 1,86.10^6 \text{ L/mol}$$

DL : nanomol/L

90% dye quenched

$$R_{o/CuL} = 2.2 \text{ nm}$$

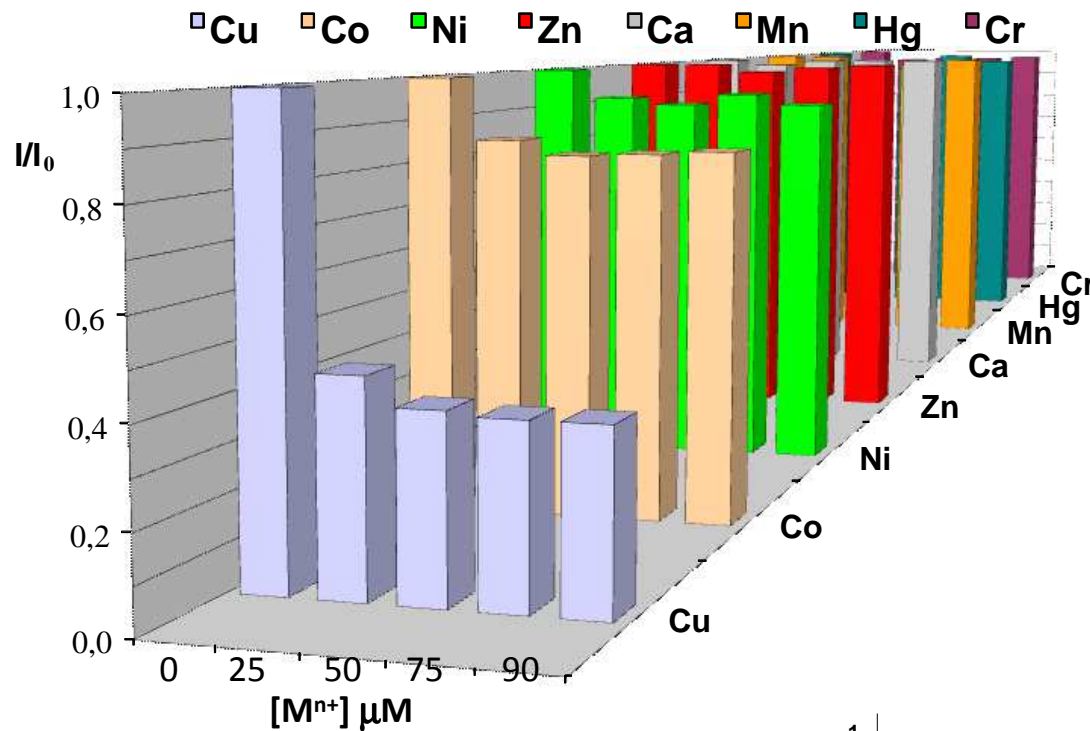
$$d_c \sim 3.3 \text{ nm}$$

$$V_{\text{acces}} \sim 80 \% V_{NP}$$

\curvearrowright R_o Dye - CuL

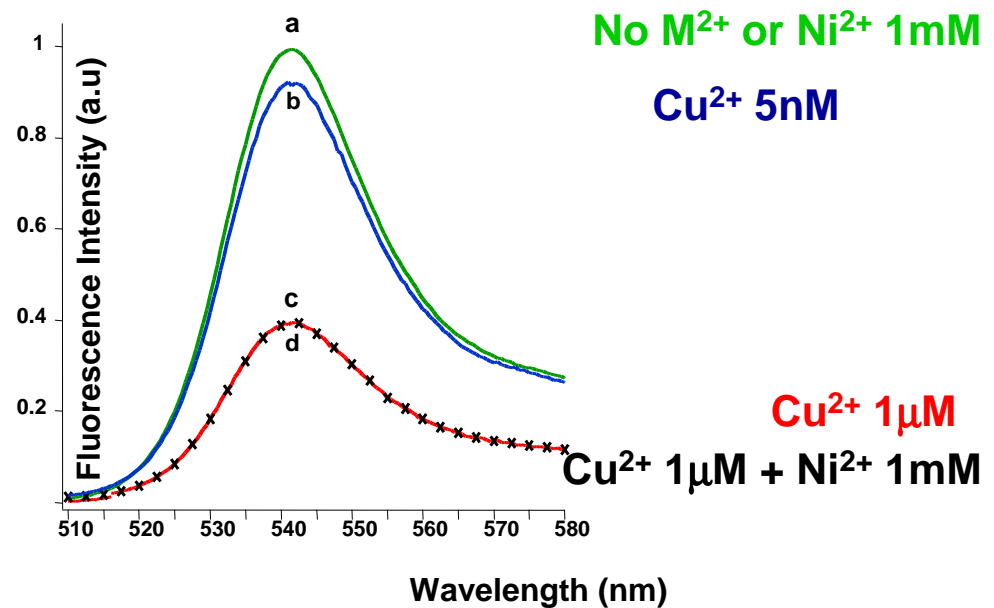
\curvearrowright Taille des NPs

Nanocapteurs Fluorescents: Sélectivité



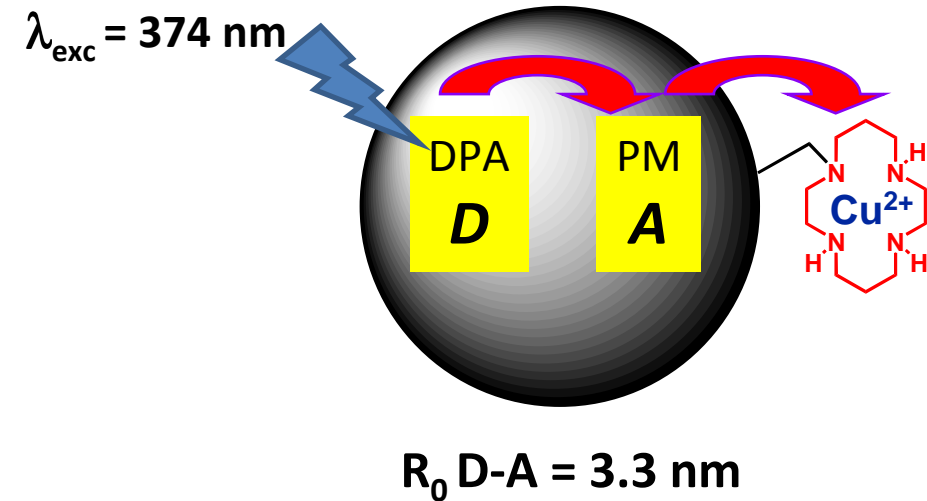
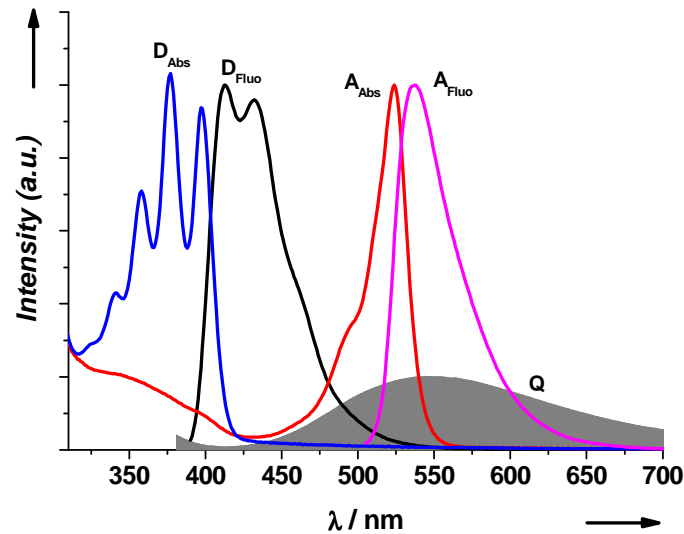
Détection spécifique de Cu²⁺

Pas d'interférence des autres cations



Nanoparticules Bi-fluorescentes

Détection par FRET en Cascade

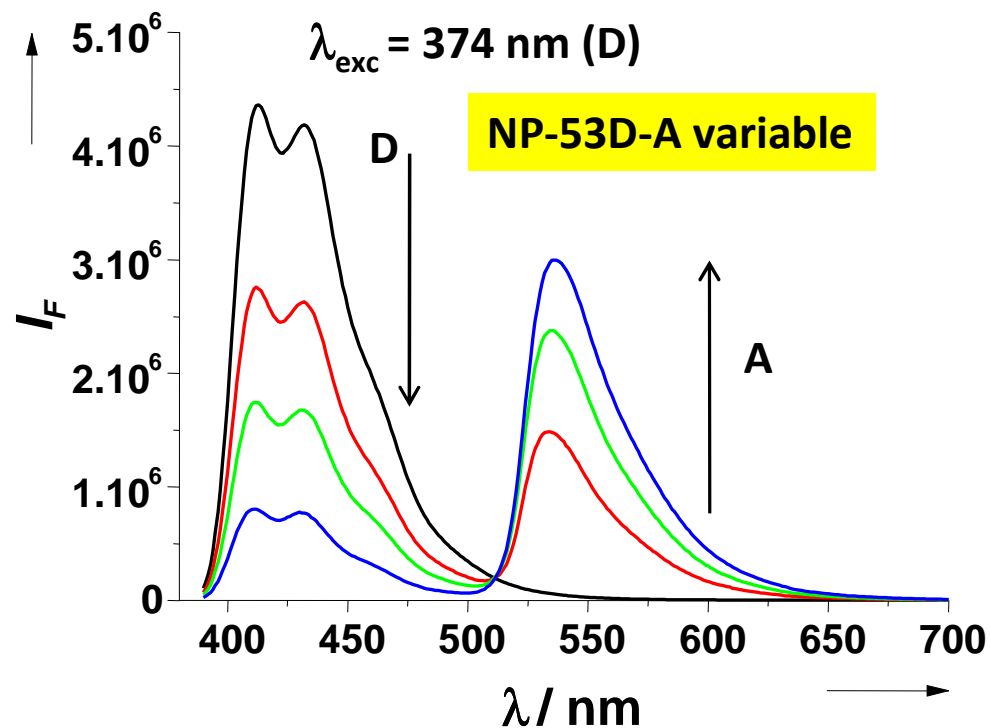


Préparation : 2 encapsulations successives

- 1) DPA (Donneur : D)
- 2) PM 567 (Accepteur : A)

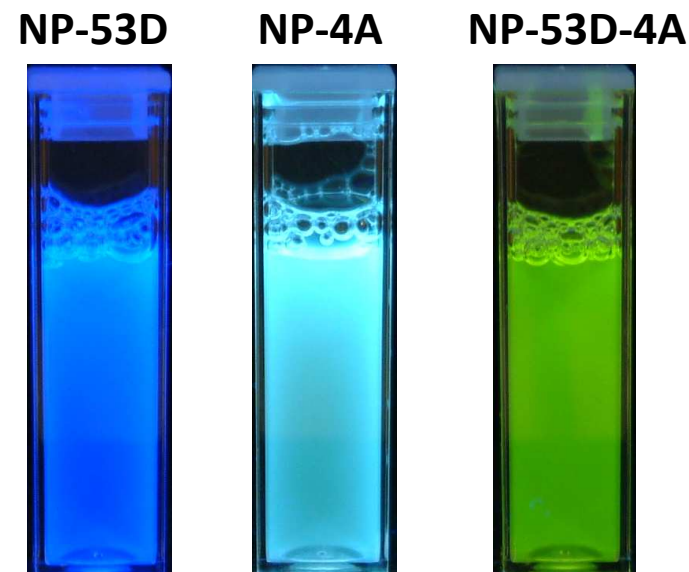
Rapport Donneur / Accepteur modulable => propriétés modulables

Nanoparticules Bi-fluorescentes

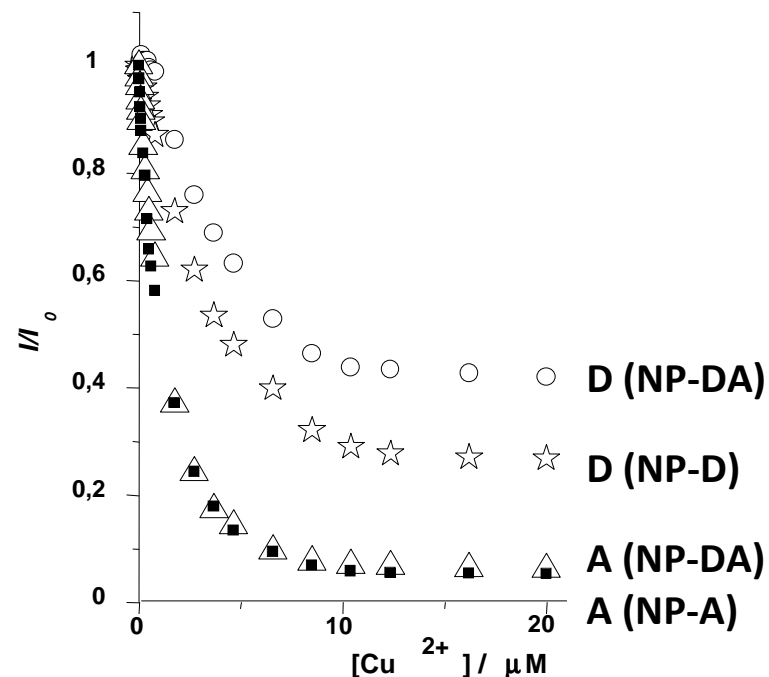
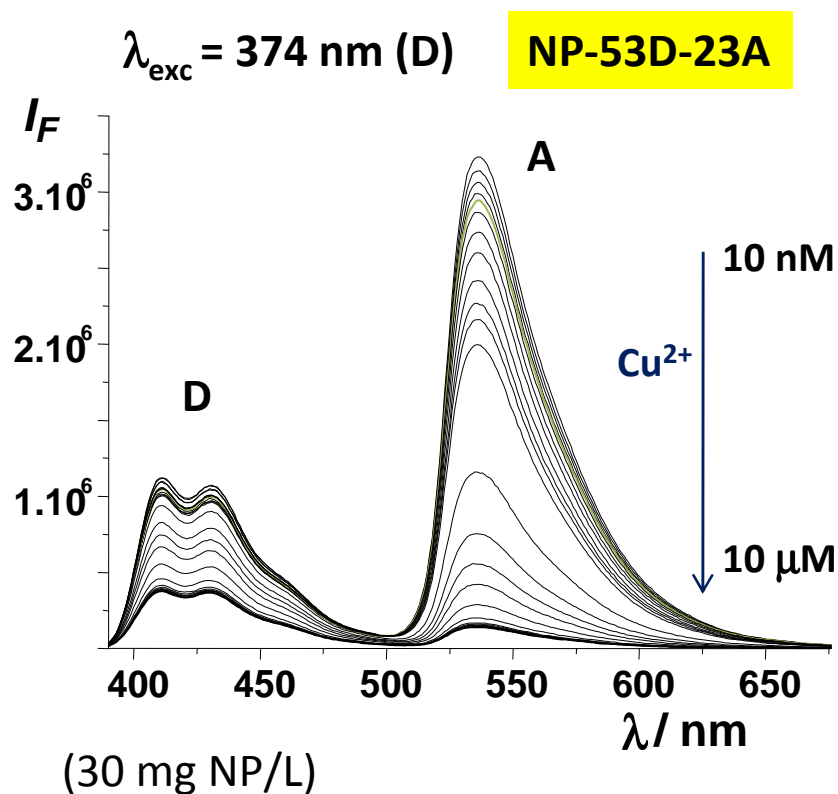


	<i>Efficacité Transfert</i>	<i>Gain Int. A</i>
NP- 53D		
NP- 53D-4A	36%	x 9,2
NP- 53D-10A	60%	x 6,5
NP- 53D-23A	80%	x 4

**Propriétés modulables
par le rapport D/A**



Détection d'ions cuivriques



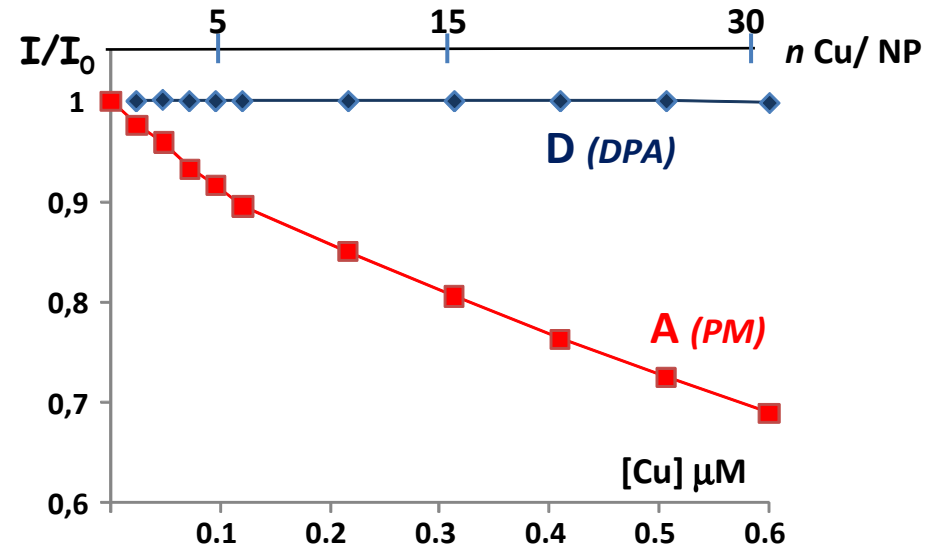
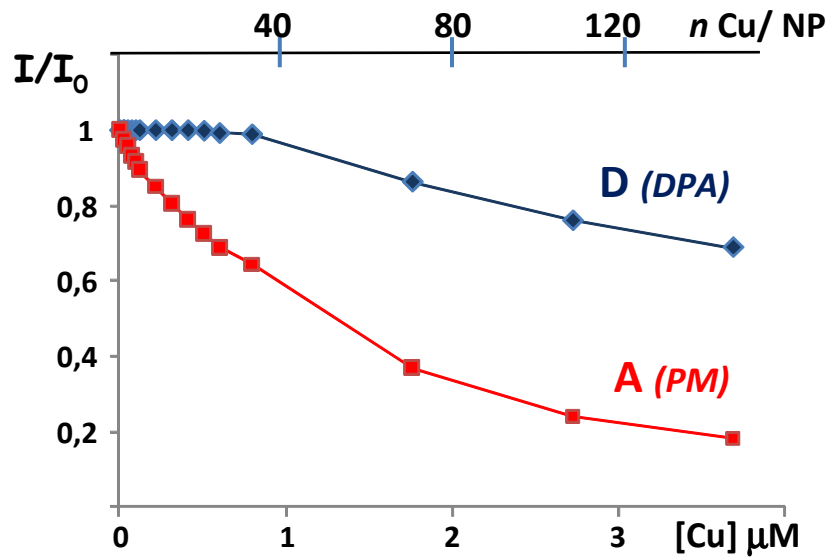
Transfert D \rightarrow A favorisé par rapport au Transfert D \rightarrow Complexe Cu(II)

Transfert A \rightarrow Complexe Cu(II) non modifié en présence de D

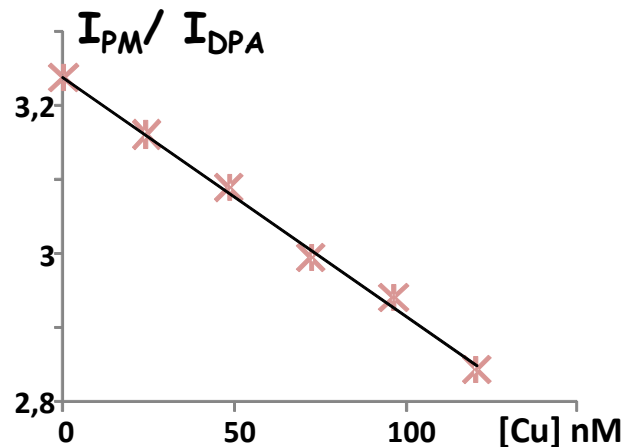
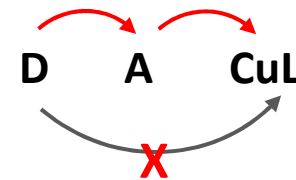
Limite de détection: 20 nM

1 Cu^{2+} par particule

Détection ratiométrique d'ions cuivriques



[Cu] < 10⁻⁷ M moins de 40 Cu / NP



⇒ Détermination ratiométrique de concentrations nanomolaires en ions Cu²⁺

Excitation à une longueur d'onde unique

Conclusions

Nanoparticules Polymériques : plateformes flexibles

↪ *Fonctionnalisation de surface*

↪ *Fluorescence modulable*

Capteurs fluorescents auto-assemblés

↪ Détection par FRET

⇒ **Modulable**

⇒ **Librairies de nanocapteurs**