

Reactivity, Solubility, Colloidal Stability: How can we predict these important properties for nanoparticles?

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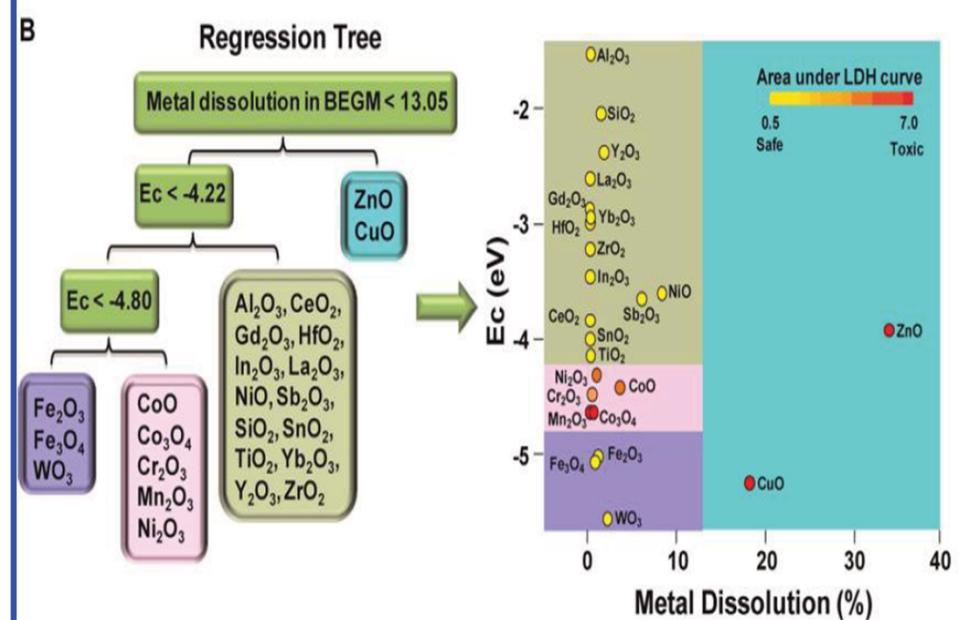
Powder Technology Laboratory

Important properties for nanoparticles

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Use of Metal Oxide Nanoparticle Band Gap To Develop a Predictive Paradigm for Oxidative Stress and Acute Pulmonary Inflammation

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Hinderliter et al. Particle and Fibre Toxicology 2010, 7:36

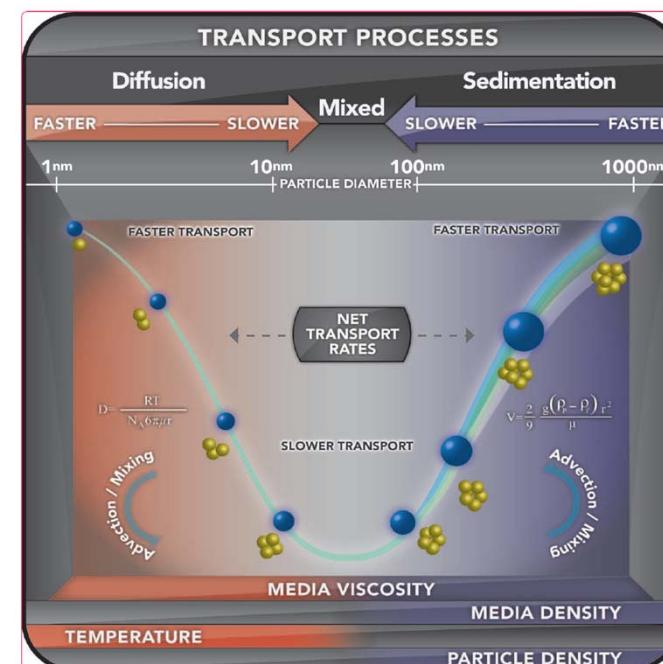


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ISDD: A computational model of particle sedimentation, diffusion and target cell dosimetry for *in vitro* toxicity studies

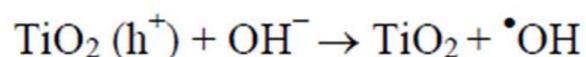
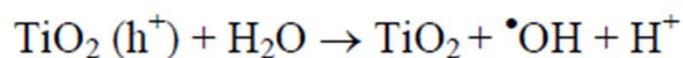
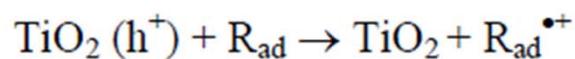
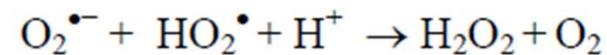
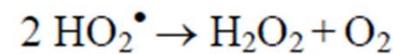
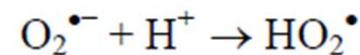
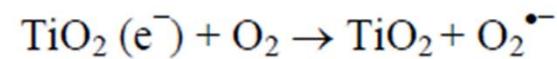
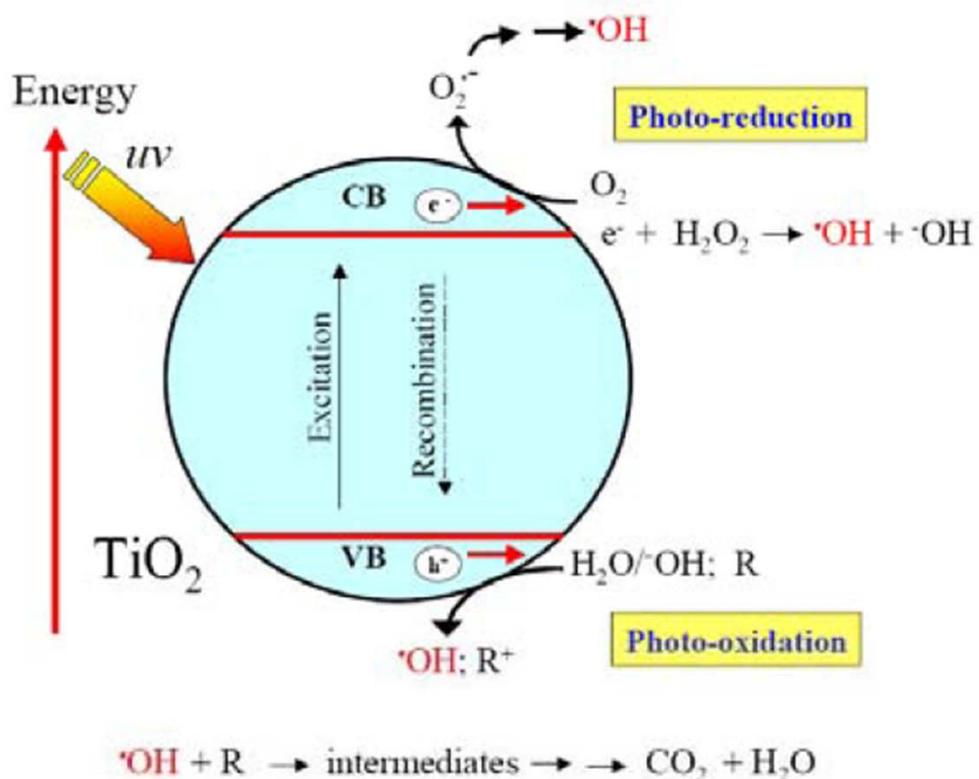
Paul M Hinderliter¹, Kevin R Minard^{1,3}, Galya Orr^{2,3}, William B Chrisler¹, Brian D Thrall^{1,3}, Joel G Pounds¹, Justin G Teeguarden^{1,3*}



Hinderliter et al. Particle and Fibre Toxicology
2010, 7:36

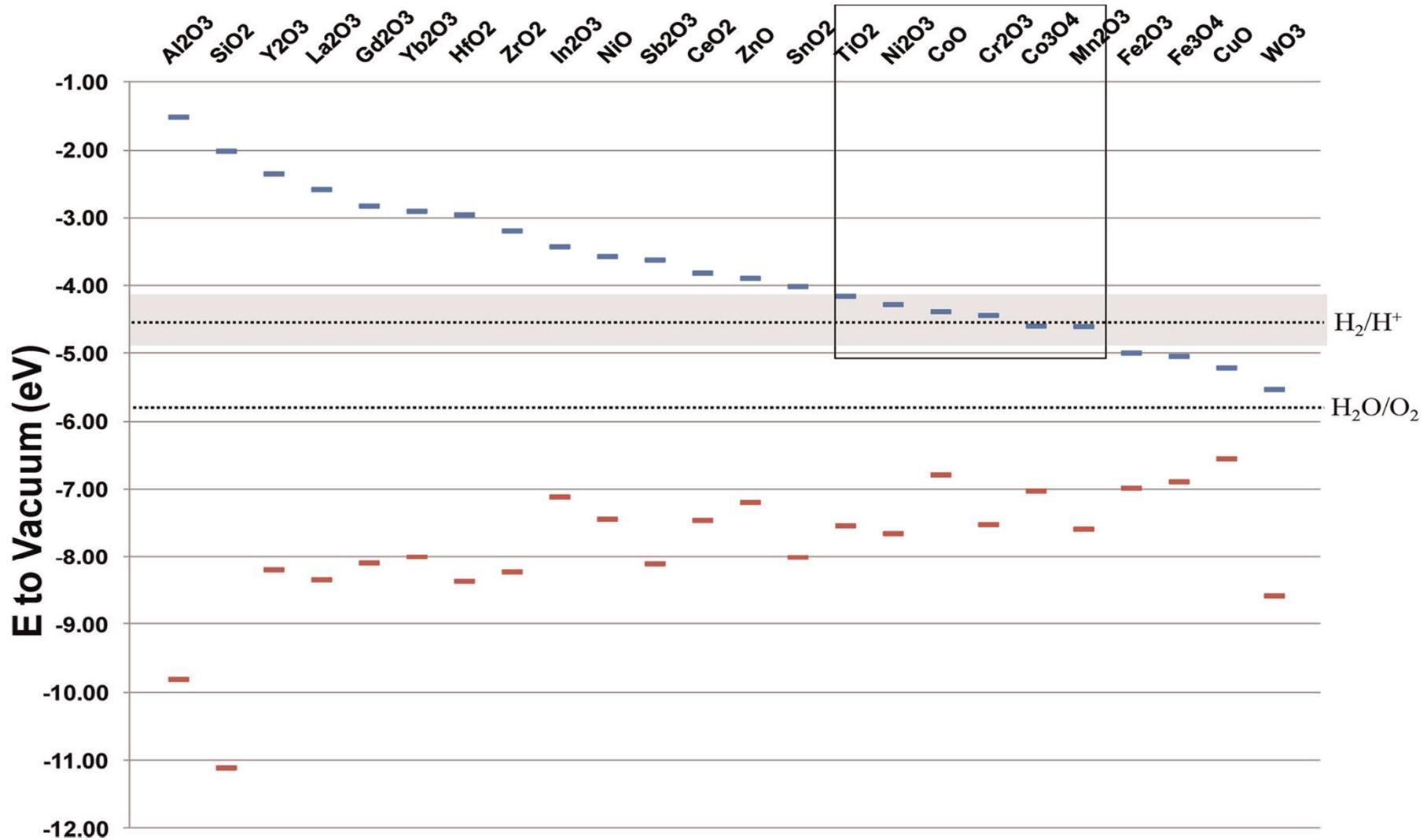
TiO₂ semiconductor photocatalysis process

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Conducting and valence band energies

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Band gap changes

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$$E^* = E_g + \frac{\hbar^2 \pi^2}{2R^2} \left[\frac{1}{m_e} + \frac{1}{m_h} \right] - \frac{1.8e^2}{\epsilon R} + \text{smaller terms} \quad (1)$$

$$E_c = -\chi_{oxide} + 0.5E_g + 0.059(PZZP - pH) \quad (2)$$

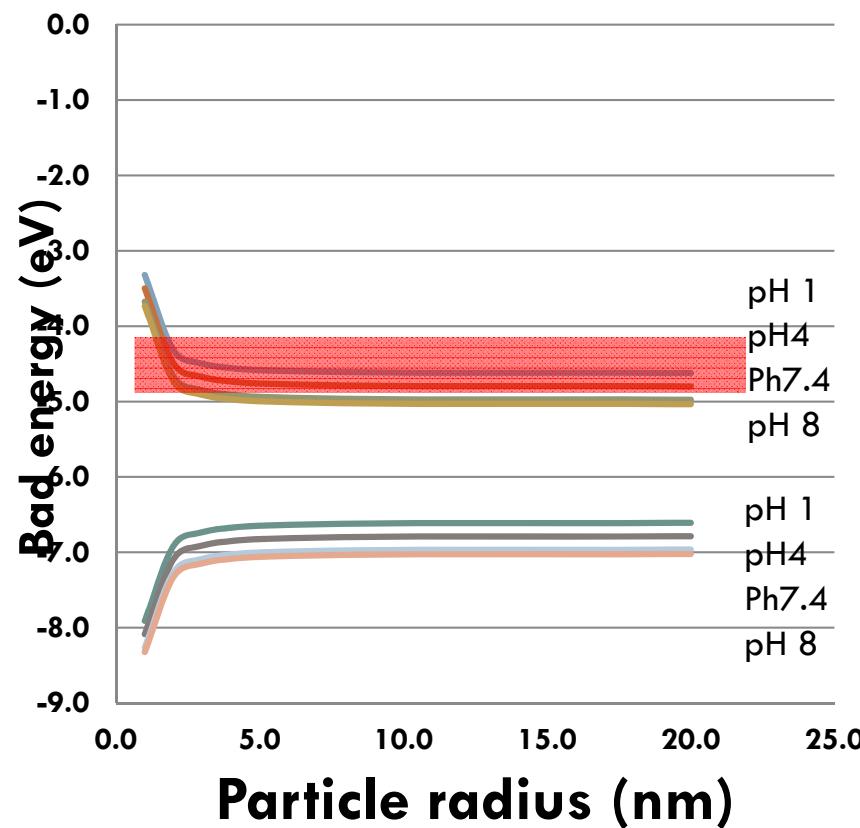
$$E_v = -\chi_{oxide} - 0.5E_g + 0.059(PZZP - pH) \quad (3)$$

with χ_{oxide} , the absolute oxide electronegativity and $PZZP$, its point of zero zeta potential.

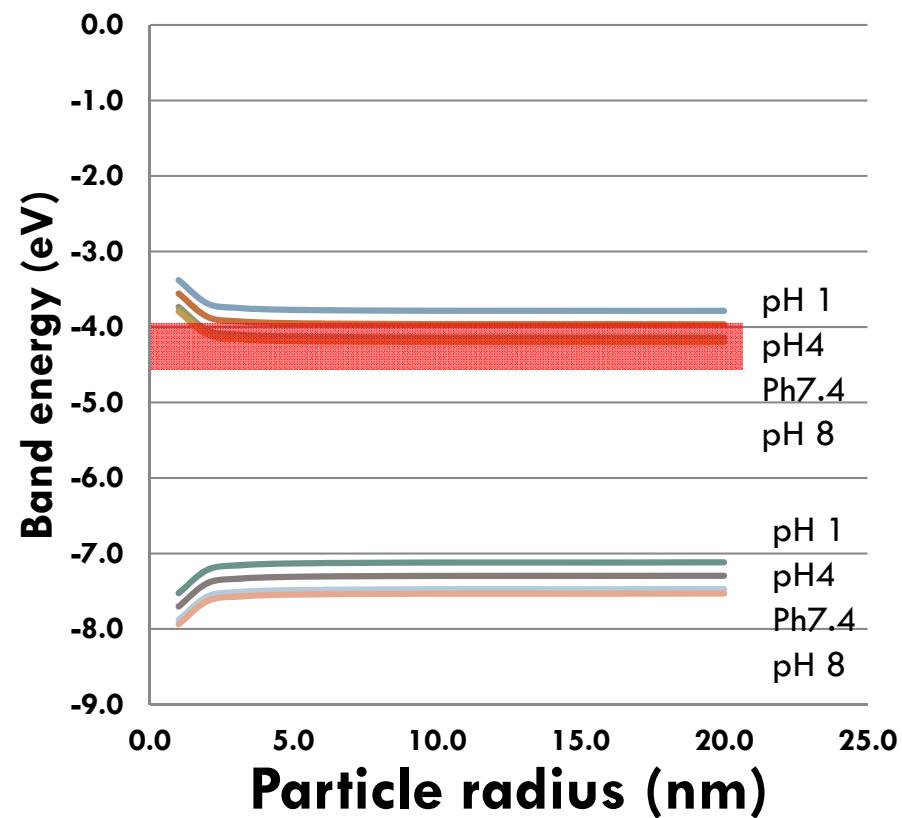
Influence of size an pH on band energy

6

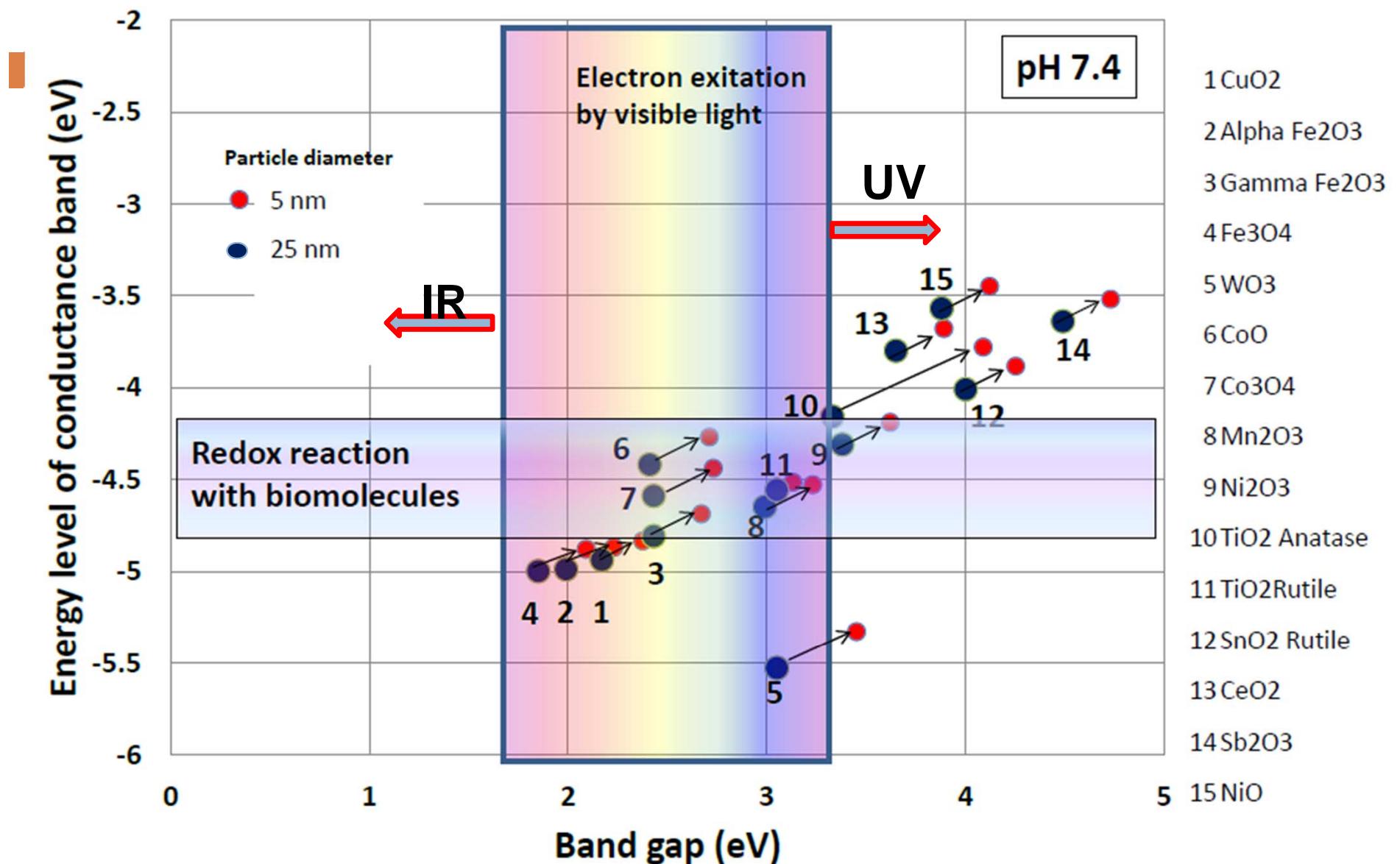
Fe_2O_3



TiO_2 (anatase)



Physico-chemical reactivity of Nanoparticles



Solubility

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**Kelvin equation
(Liquid droplet)**

$$RT \ln \frac{p^\beta(T, r)}{p^\beta(T, \infty)} = \frac{2\gamma^\alpha}{r}$$

**Gibbs equation
(Solid particle)**

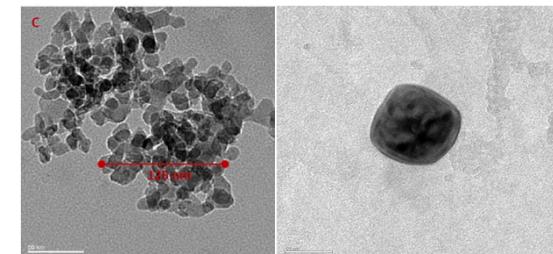
$$\begin{aligned}\mu_1^s(T, r) &= \mu_1^s(T, \infty) + \frac{2\gamma v_1^s}{r} \\ \mu_1^l(T, r) &= \mu_1^{0,l} + RT \ln(y_1^l c_1^l)\end{aligned}$$

**Thomson Freundlich
equation**

$$c_1^l(r) = c_1^l(\infty) \exp \left[\frac{2\gamma v_1^s}{RT} \frac{1}{r} \right]$$

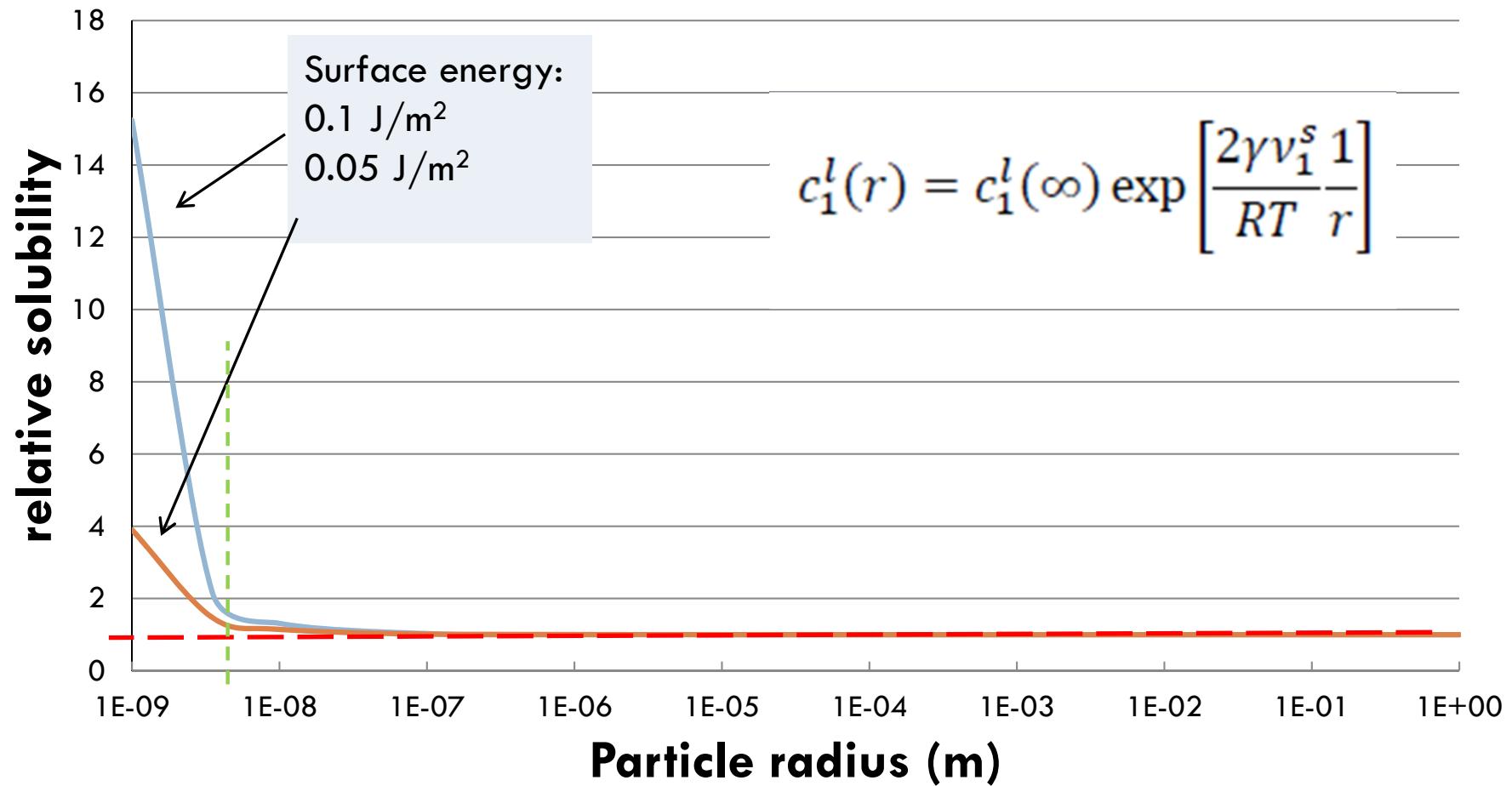
Vogelsberger (2003)

Also valid for faceted nanoparticles ??



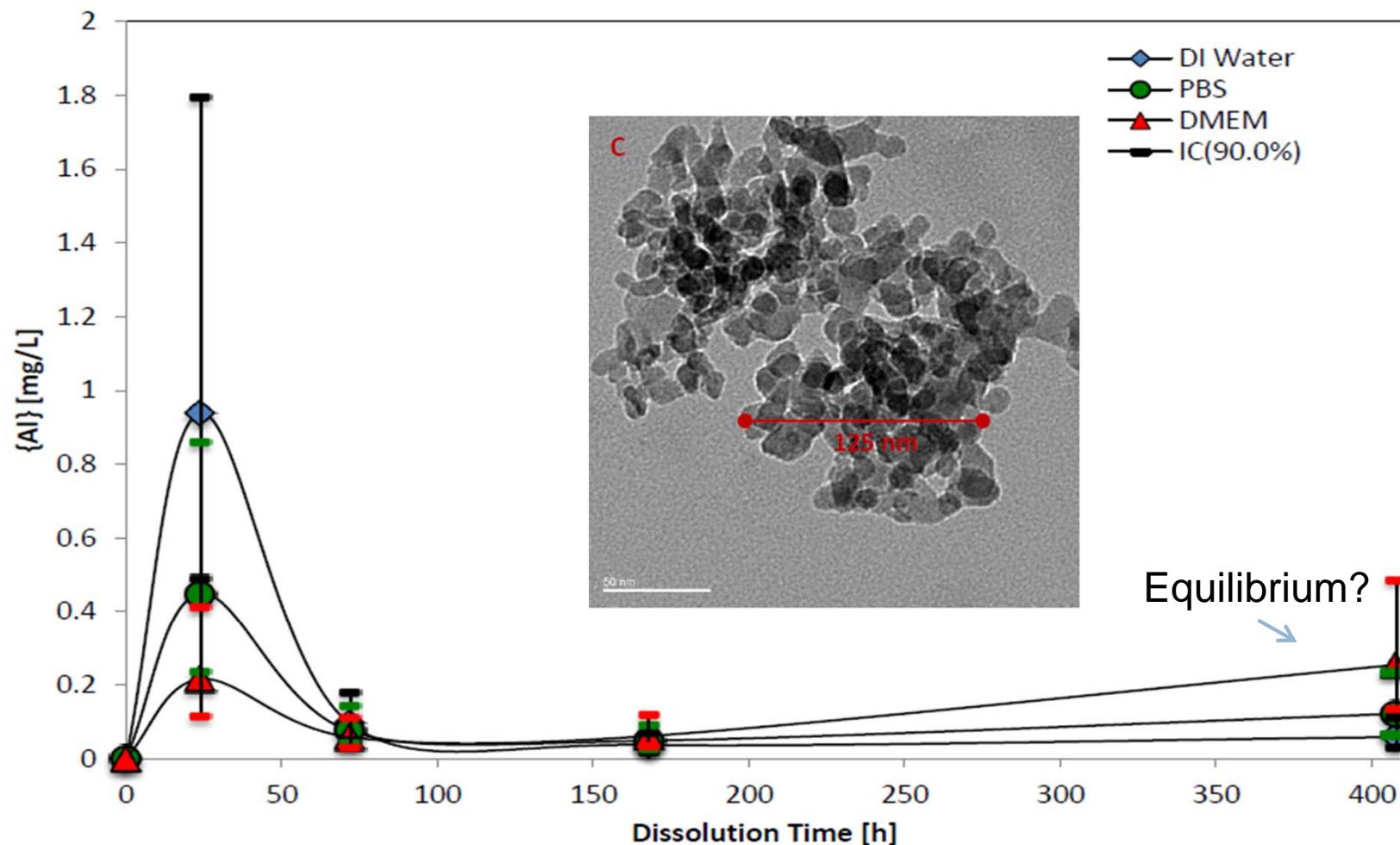
Relative solubility of Fe₂O₃ particles

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Kinetic aspects of solubility

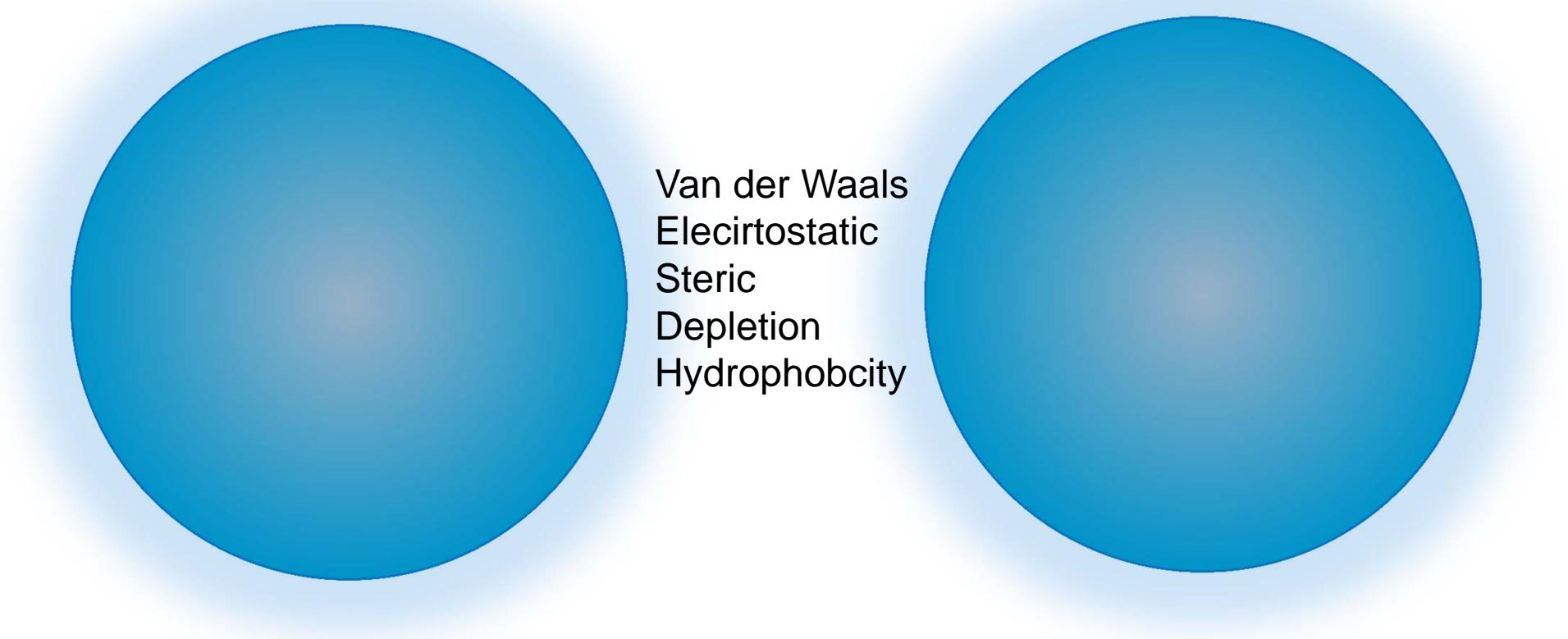
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For theoretical consideration see Vogelsberger et al. J Phys Chem B, vol 107, 9671 (2003)

Colloidal interaction

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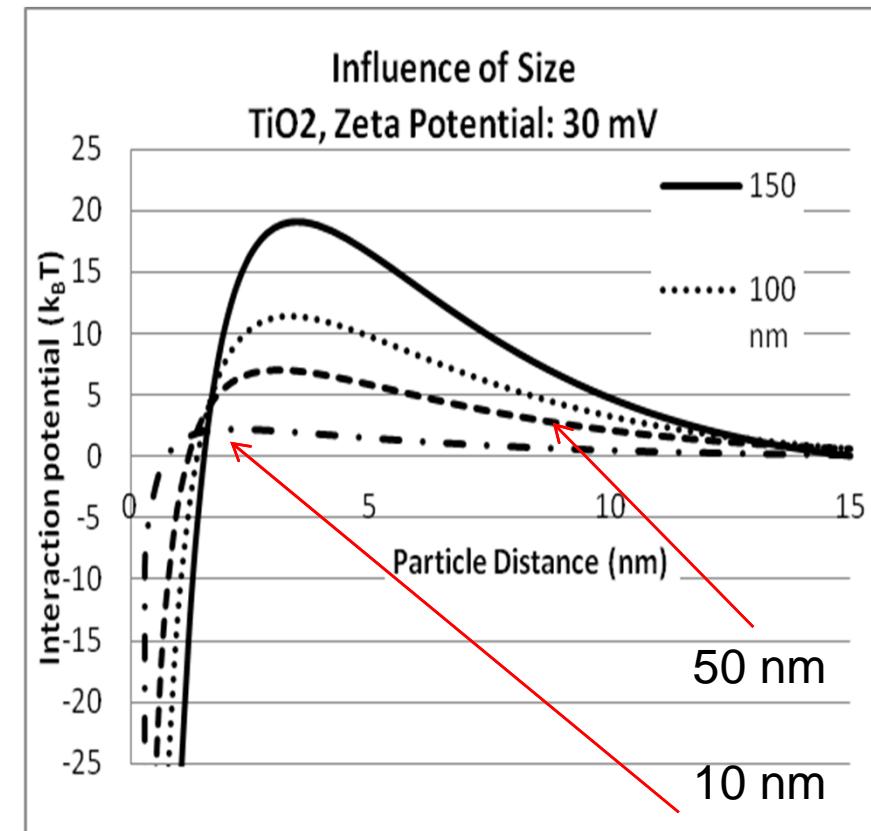
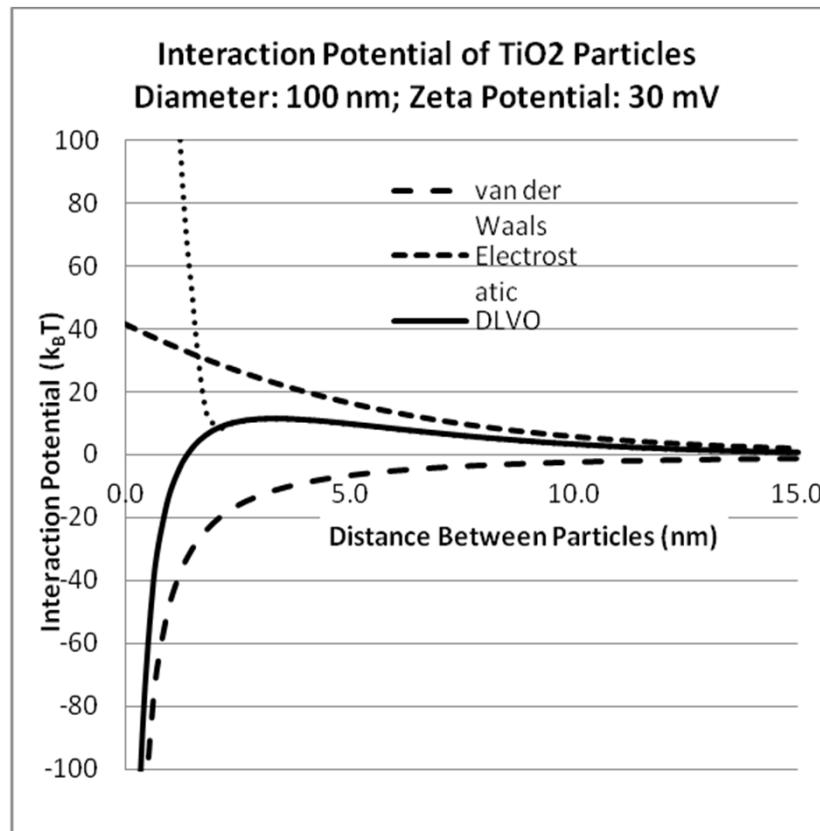


Van der Waals
Electrostatic
Steric
Depletion
Hydrophobicity

Dielectric function (Material, solvent)
Surface charge
viscosity

Influences on colloidal stability

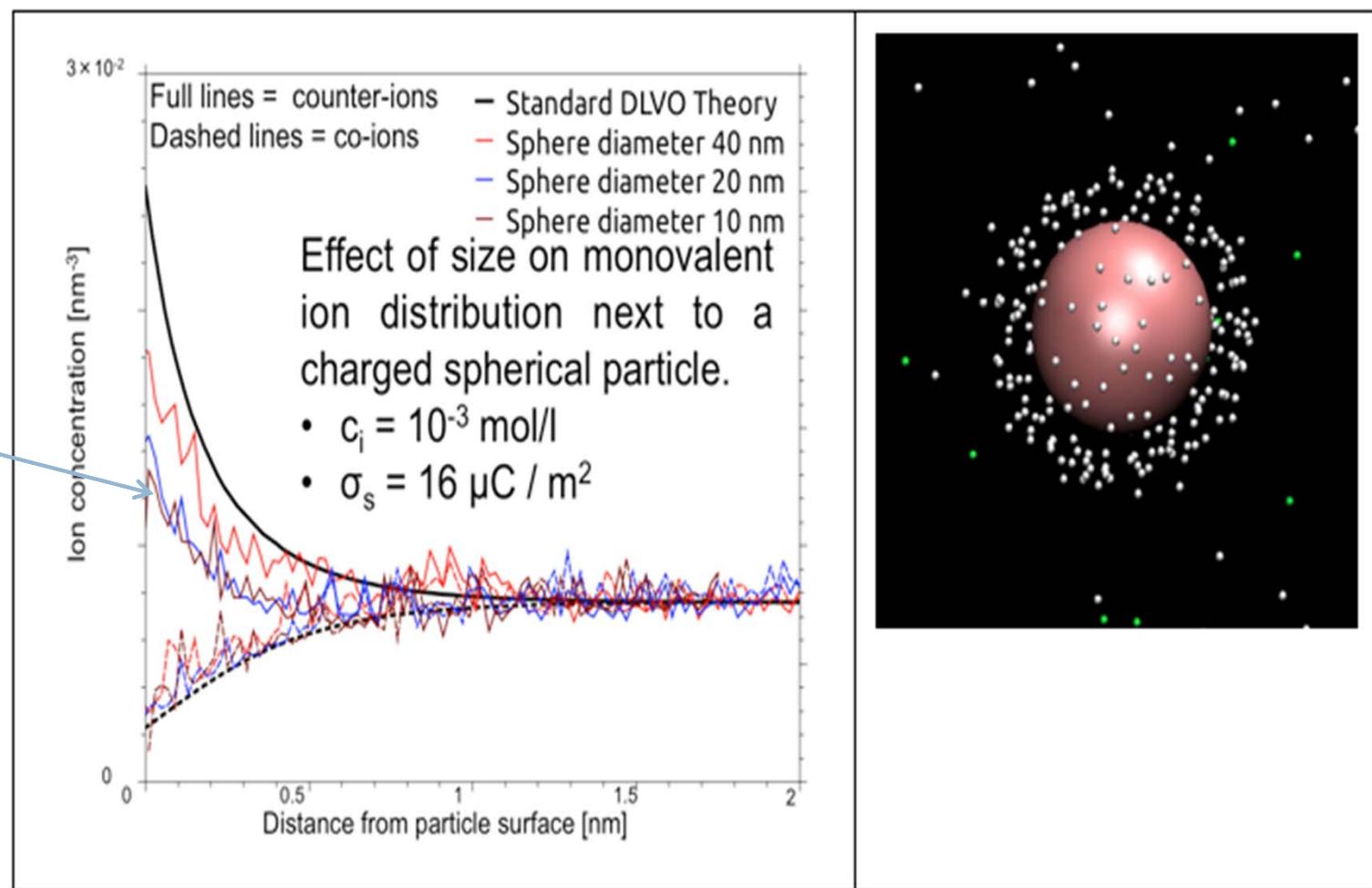
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Colloidal Stability of Nanoparticles

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Reduced amount of counter ions

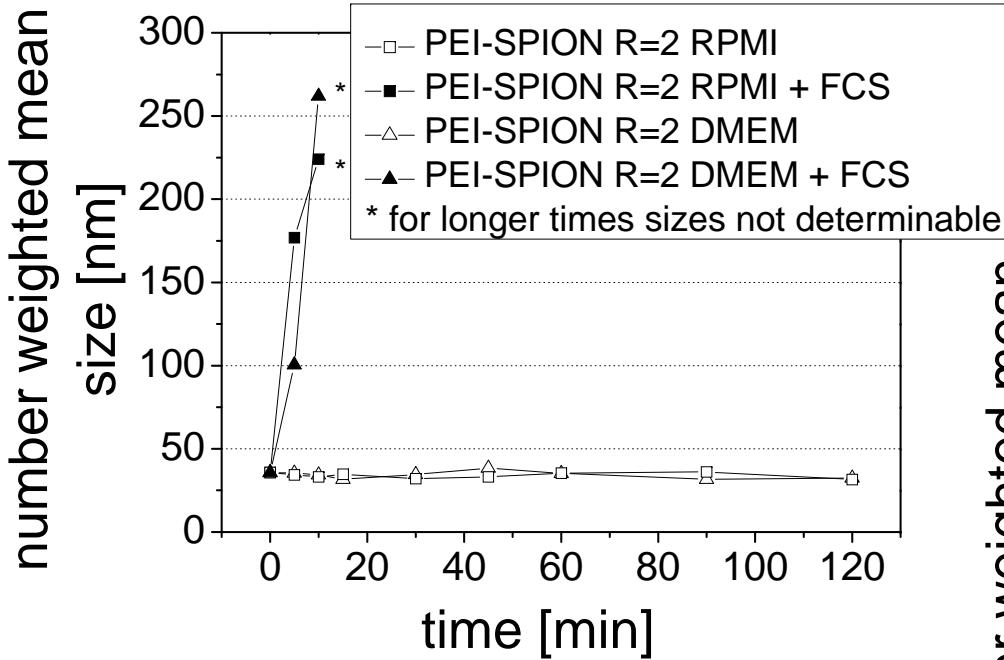


Vianney Bernau, EPFL-LTP

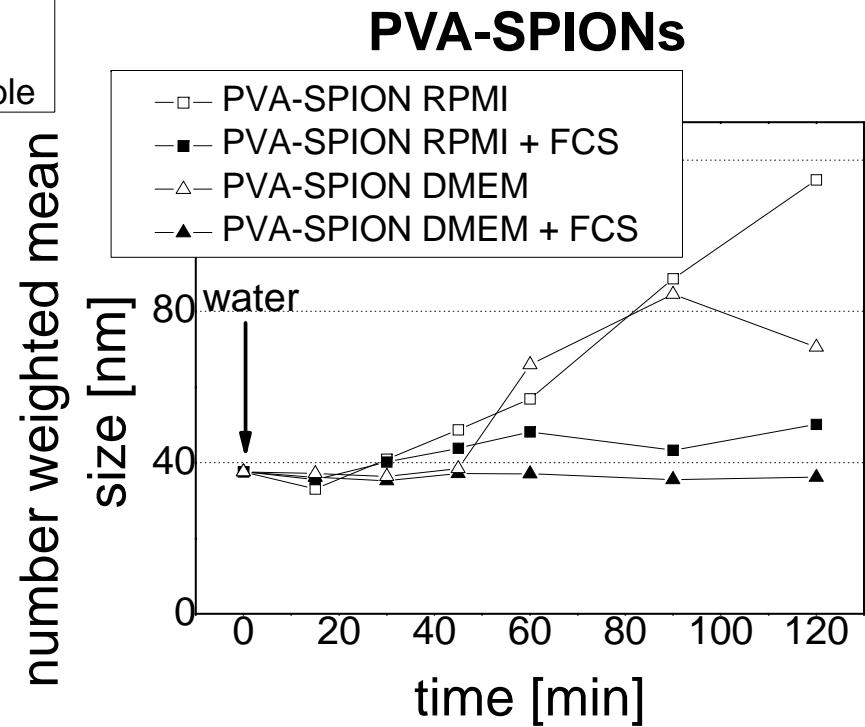
Particles in biological media

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EPFL



PEI-SPIONS



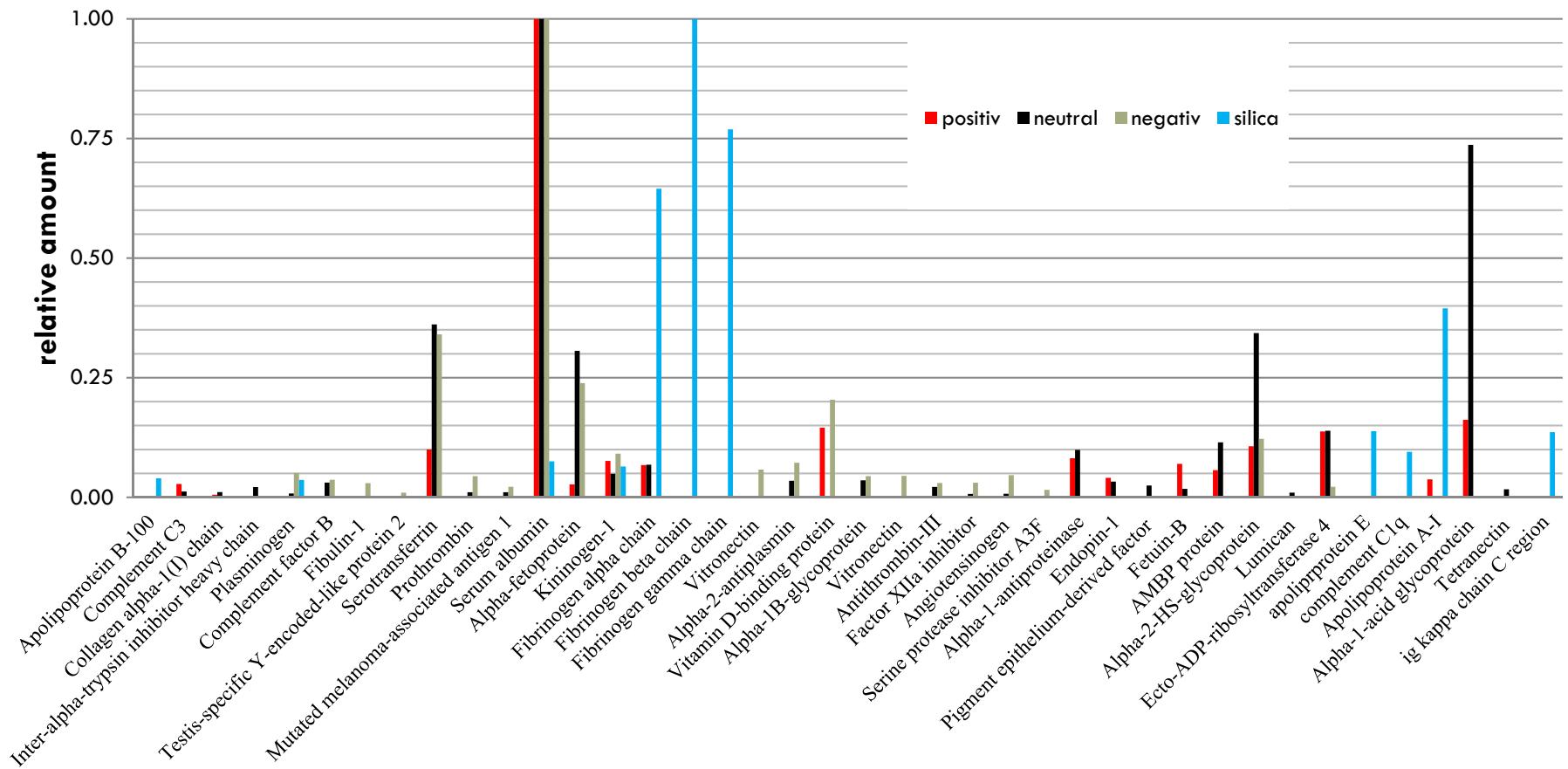
Colloidal stability = **f(coating, charge and of protein adsorption)**

Application of DLVO theory is not possible

Impact on transport properties during in vitro experiments

Influence of surface composition and charge on protein adsorption

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Comparison of protein adsorption in vitro /in vivo (rat serum and rat)

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Time	Mw (Da)	Protein description	pl
15 min	15979	Hemoglobin subunit beta-1	7.87
	68731	Serum albumin	6.09
+ 7 days	186459	Complement C3	6.12
	11367	Histone H4	11.3 6
15 min	37982	Alpha-2-HS-glycoprotein	6.05
	41737	Actin, cytoplasmic 1	5.29
	41793	Actin, cytoplasmic 2	5.31
	54235	Fibrinogen beta chain	7.89
	86686	Fibrinogen alpha chain	5.51
	272509	Fibronectin	5.5
	15329	Hemoglobin subunit alpha-1/2	7.81
7 days	15982	Hemoglobin subunit beta-2	8.91
	35753	Apolipoprotein E	5.23
	76395	Serotransferrin	7.14
	167124	Alpha-1-macroglobulin	6.46

- Roughly 60% of the proteins adsorbed in vivo could not be detected at particles after injection in rats (in vitro adsorption)
- In vitro: Positive charged particles show lower protein adsoption as neutral and negativ charged particles,
- in vivo: the opposite was detected

Usawadee Sakulkhu, EPFL-LTP, Thesis
Publication in preparation

Conclusions

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- Physical and chemical changes of the material properties mostly for particles < 15 nm in diameter
- Solubility in the first 100 h could be 2 to 10 times higher than in equilibrium (influence on toxicity studies?)
- Counter ion concentration is lower around nanoparticles → changes colloidal stability
- Charges and material influences the protein adsorption → different colloidal stability and interaction with cells
- *In vivo* protein adsorption is very different from *in vitro* adsorption → impact on tox studies and prediction of behavior of nanoparticles *in vivo*?

Thank you for your attention

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