

# Forces d'interactions colloïdales

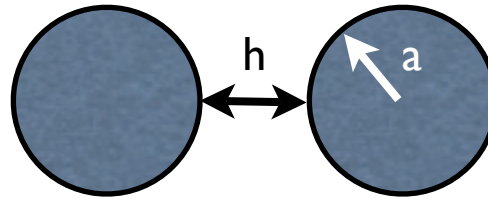
**HS40**

40wt%

$a = 12 \pm 2 \text{ nm}$

densité silice: 2.2g/ml

pH=9.0



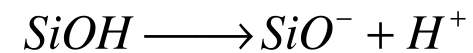
## interaction de Van der Waals

origine dipôle-dipôle

$$W = -\frac{A}{6} \left( \frac{2a^2}{r^2 - 4a^2} + \frac{2a^2 + \ln(r^2 - 4a^2)}{r^2} \right)$$

A: constante de Hamaker  $A = 0.83 \times 10^{-20} \text{ J}$

## interaction électrostatique



$$W_e = 32\pi\epsilon a \left( \frac{kT}{ze} \right) th^2 \left( \frac{ze\Psi_0}{4kT} \right) \exp\left( -\frac{h}{\lambda_D} \right)$$

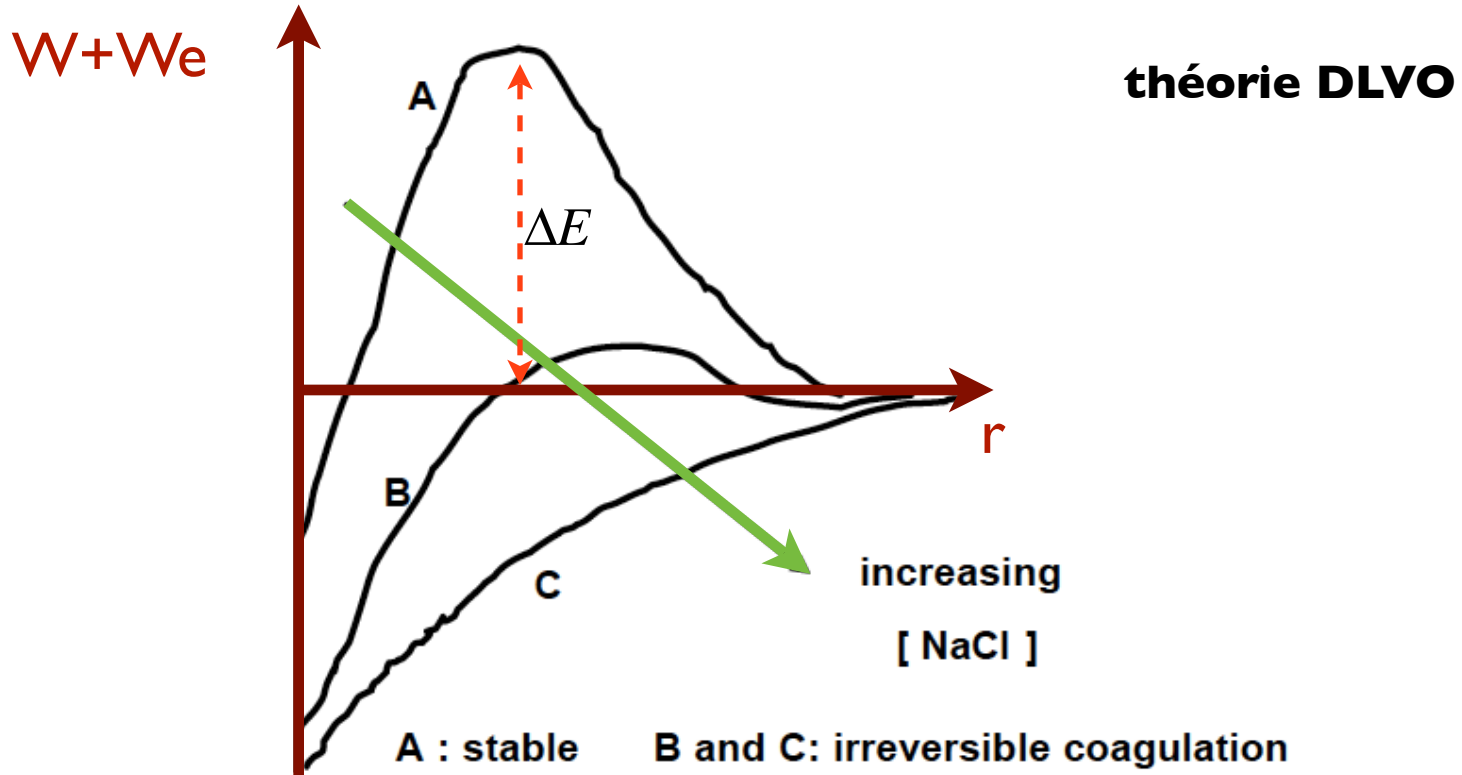
$\Psi_0$  : potentiel de surface de la particule

longueur de Debye  $\lambda_D = \left( \frac{2000e^2NC}{\epsilon\epsilon_0kT} \right)^{-1/2}$

⇒ plus la concentration en sel, C, augmente,  
plus la longueur de Debye diminue

écranage des charges de surface

# Energie d'interaction en fonction de la distance entre particules

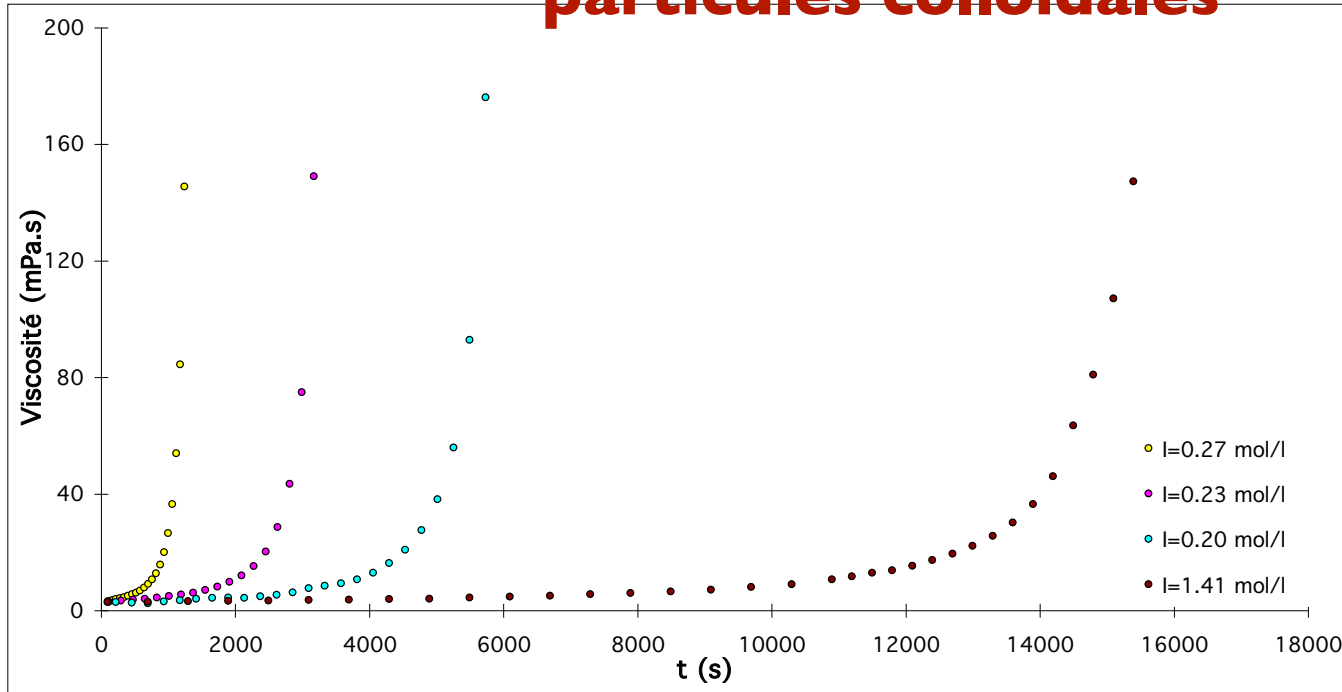


**A:**  $\Delta E \gg kT$  la suspension est stable

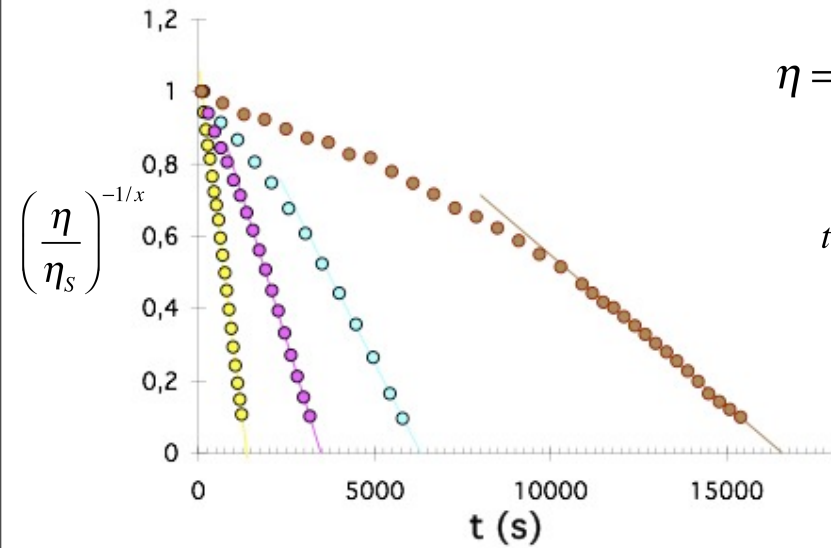
**B:**  $\Delta E \sim kT$  : les particules vont s'agréger lentement, la suspension est instable

**C:** Van des Waals prépondérant système instable

# Mesure de la viscosité au cours de l'agrégation de particules colloïdales

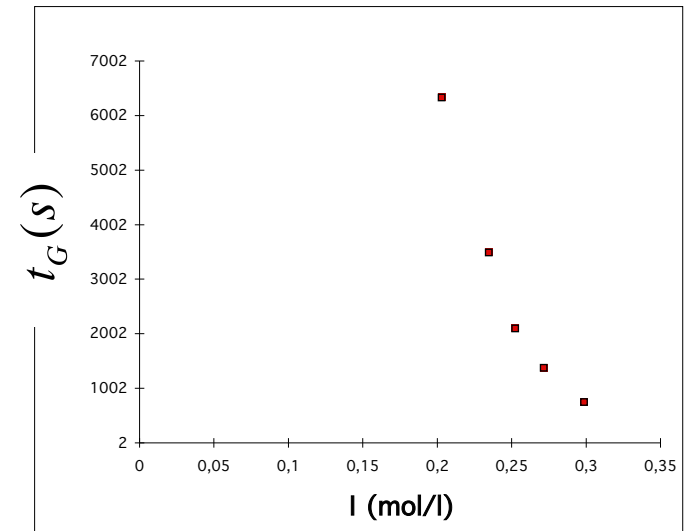


NaCl  
 $\Downarrow$   
 force ionique I  
 =  
 concentration C



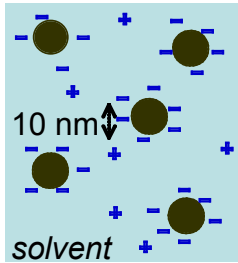
$$\eta = \eta_s \frac{1}{(t - t_G)^x} \Rightarrow t_G$$

$$t_G = t_0 \exp\left(-\frac{\Delta E}{kT}\right)$$



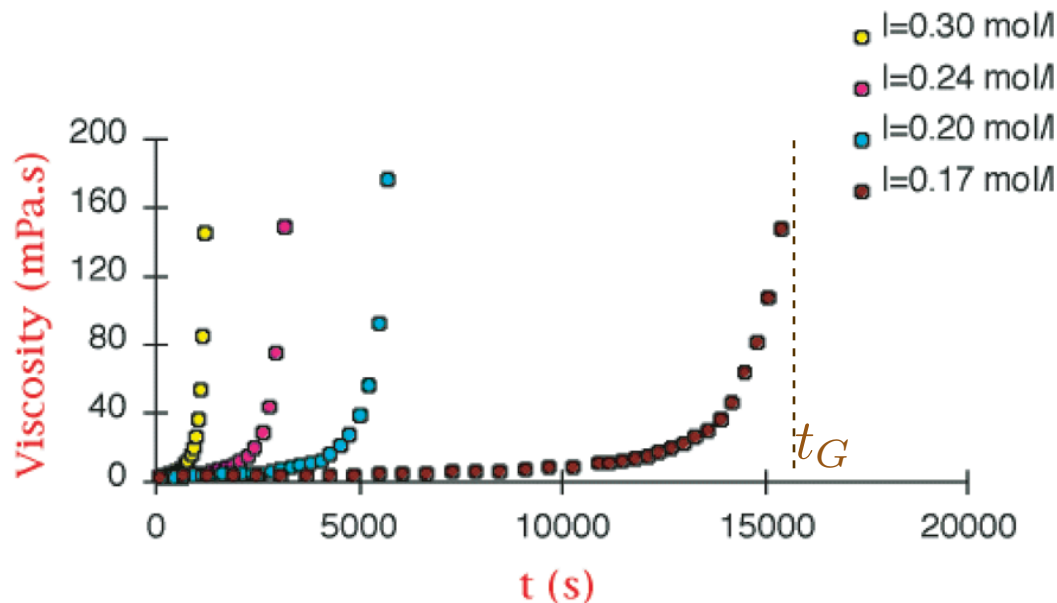
# 2 coupled effects in the sol-gel transformation

## Gelation kinetics



influence of the ionic strength,  $I$ :  
screening charges borne by particles

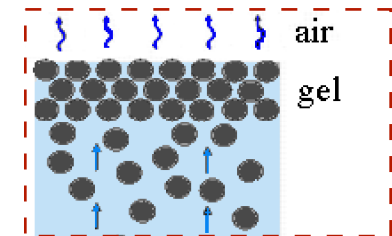
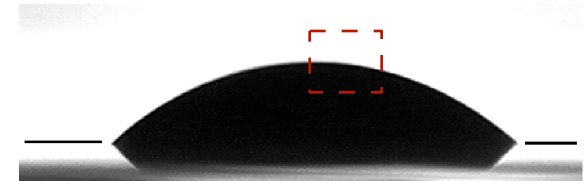
suspension viscosity increases as aggregates form



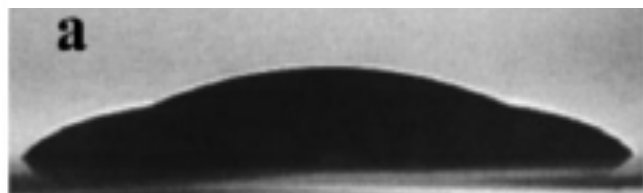
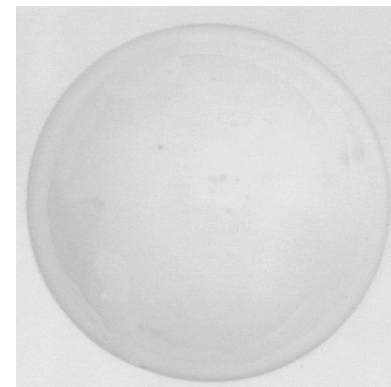
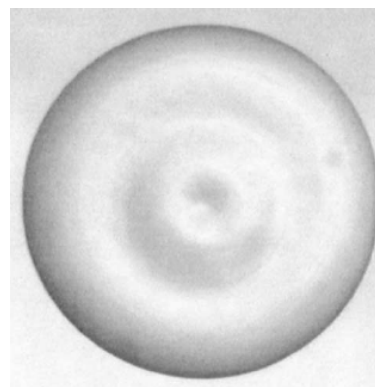
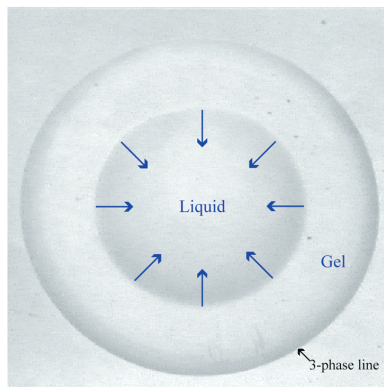
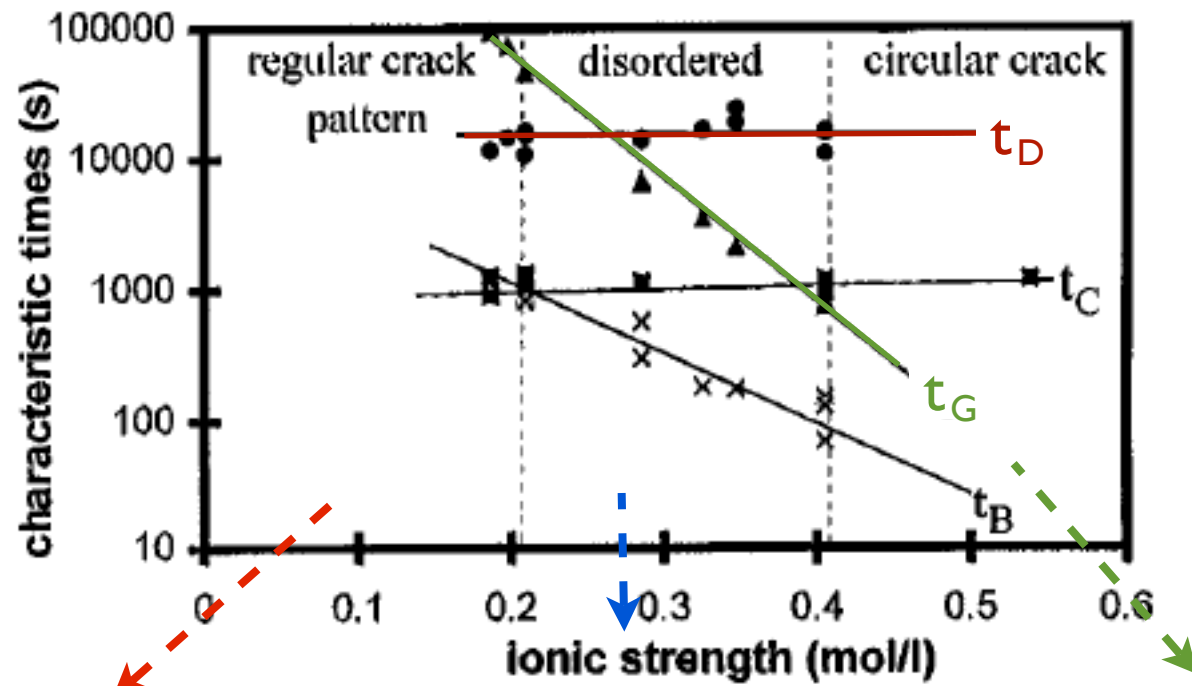
gelation time  $t_G$

## Drying kinetics

evaporation of solvent



$$\text{drying time } t_D = \frac{R_0}{\dot{V}_E} \cdot \frac{V_0}{R_0 S_0}$$

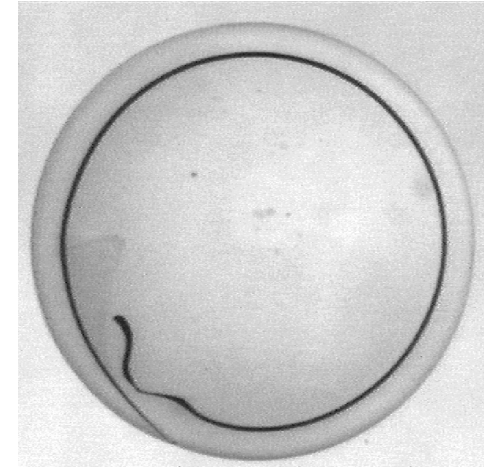
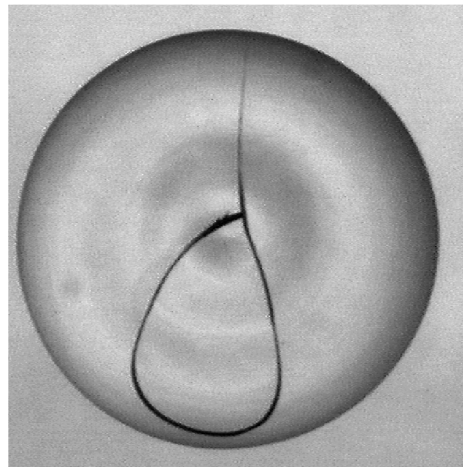
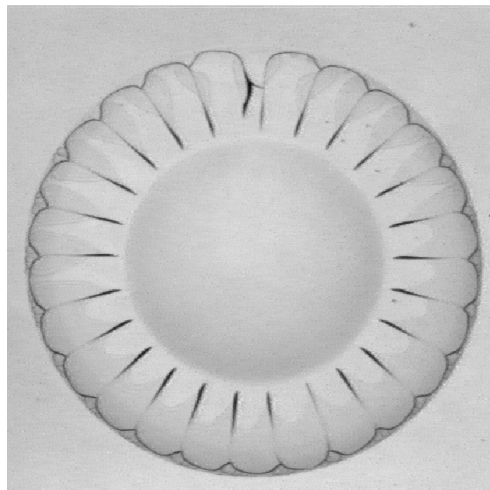
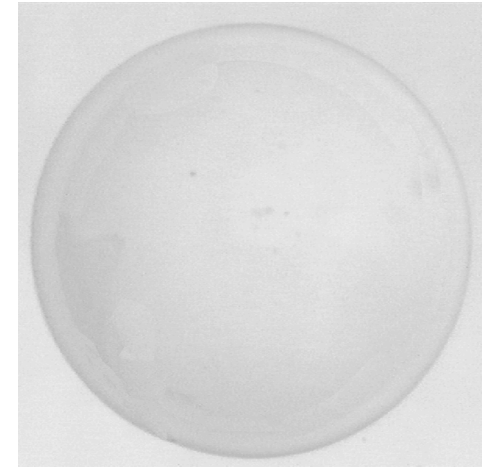
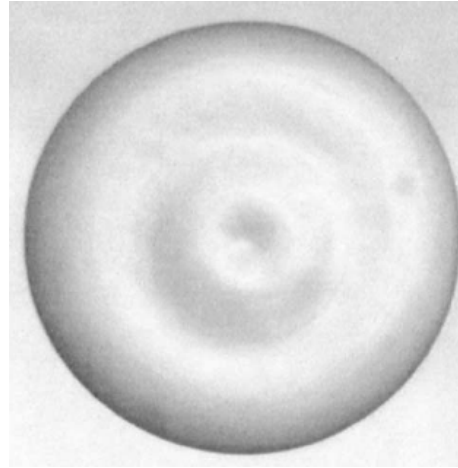
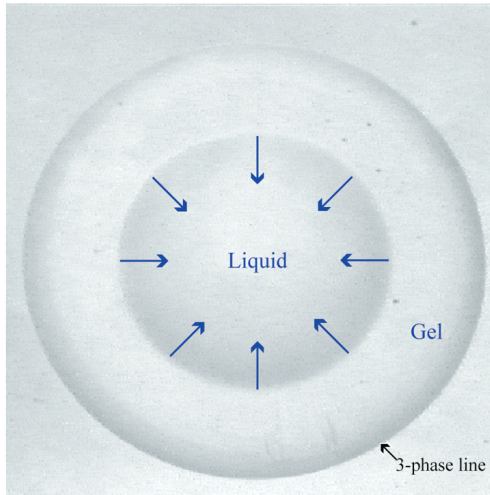


# Figures de fractures induites par séchage de gouttes

$$t_G/t_D > 10^2$$

$$10^{-1} < t_G/t_D < 10$$

$$t_G/t_D < 10^{-2} \text{ force ionique}$$



Influence of the salt content on the crack patterns formed by colloidal suspension desiccation  
L. Pauchard, F. Parisse, C. Allain Phys. Rev. E, 59, 3737 (1999)

# Contraintes mécaniques induites par séchage

évaporation  $\Rightarrow$  **contraintes de rétraction d'origine capillaire**

$$p_c = \frac{2\gamma_{air/eau}}{r_{pore}} = \frac{2 \times 73 \cdot 10^{-3}}{20 \cdot 10^{-9}} \approx 10^7 \text{ Pa}$$

influencées par:

- effets de la présence de surfactants (réduction de la pression capillaire)
- perméabilité de la structure poreuse
- rigidité de la structure poreuse
- cinétique du séchage
- de l'adhésion sur le substrat

$$\dot{V}_E = -\frac{\kappa}{\eta} \nabla P \Big|_{z=h} \quad \text{loi de Darcy}$$

$\kappa$  : perméabilité

$$\kappa = \frac{1}{180} \frac{K^3}{(1-K)^2} (2r_{pore})^2 \quad \text{loi de Carman-Kozeny}$$

$K$ : porosité