Evaporation of colloids droplets containing PBS

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Colloids

Everyday life :

Particles suspension



$k_BT \gg \rho g R^4$

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Colloids

Everyday life :

Particles suspension



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Colloids

Everyday life :





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$k_B T \gg \rho g R^4$

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Everyday life :





Colloids

$k_B T \gg \rho g R^4$

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Everyday life :



Colloids





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$k_BT \gg \rho g R^4$

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Everyday life :





Colloids

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Colloids

Everyday life :









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$k_BT \gg \rho g R^4$

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Everyday life :



 $k_B T \gg \rho g R^4$

Colloids

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Colloids

Blood deposits : health indicator (?)



T.A. Yakhno et al., IEEE Eng. Med. Biol. Mag., <u>24(2)</u>, 96 (2005)

- Important parameters?
- Physical mechanisms ?
- ⇒ Study of colloids droplets evaporation

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Colloids

Blood deposits : health indicator (?)



T.A. Yakhno et al., IEEE Eng. Med. Biol. Mag., <u>24(2)</u>, 96 (2005)

 Important parameters?

- Physical mechanisms ?
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Colloids

Blood deposits : health indicator (?)

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- Important parameters ?
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Coffee Ring

Dominant effect : coffee ring



Robert D. Deegan et al., Nature 3896653, p.827-829 (1997)

Coffee Ring

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Pinning of contact line and evaporation profile Dominant effect : coffee ring

Robert D. Deegan et al., Nature 3896653, p.827-829 (1997)

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Marangoni effect



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PBS properties

Phosphate-buffered saline (PBS) properties :

• pH Buffer (7.4)

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PBS properties

Phosphate-buffered saline (PBS) properties :

- pH Buffer (7.4)
- Screen electrostatic repulsion



J.N. Israelachvili, Intermolecular and surface forces Academic press (2011).

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PBS properties

Phosphate-buffered saline (PBS) properties :

- pH Buffer (7.4)
- Screen electrostatic repulsion
- Increase surface tension ($\frac{d\gamma}{d\kappa} \sim 10^{-4}~{
 m N/m})$

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PIV Movie

First, let's watch some movies!

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Schematic view

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Schematic view

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Marangoni transition

$$\kappa \equiv \frac{C_i}{C_i(PBS)}$$

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Marangoni transition

$$\kappa \equiv \frac{C_i}{C_i(PBS)}$$

$$\kappa_0 \sim 10^{-2}$$

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Dynamics observations Dynamics discussion Resulting Dried Drops

Marangoni transition

$$\kappa \equiv \frac{C_i}{C_i(PBS)}$$

$$\kappa_0 \sim 10^{-2}$$

$$\kappa_m = \kappa_0 \frac{V_0}{V}$$

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Marangoni transition

$$\kappa \equiv \frac{C_i}{C_i(PBS)}$$

$$\kappa_0 \sim 10^{-2}$$

$$\kappa_m = \kappa_0 \frac{V_0}{V}$$

$$\bigtriangleup \kappa \sim \kappa_m - \kappa_0 = \kappa_0 (\frac{V_0}{V} - 1)$$

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Marangoni transition

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$$igtriangleq \kappa \sim \kappa_m - \kappa_0 = \kappa_0 (rac{V_0}{V} - 1)$$
 $Ma = rac{rac{d\gamma}{d\kappa} \ igtriangleq \kappa \ t_f}{\eta \ R}$

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Marangoni transition

$$\kappa \equiv \frac{C_i}{C_i(PBS)}$$

$$\kappa_0 \sim 10^{-2}$$

$$\kappa_m = \kappa_0 \frac{V_0}{V}$$

$$\Delta \kappa \sim \kappa_m - \kappa_0 = \kappa_0 \left(\frac{V_0}{V} - 1\right)$$
$$Ma = \frac{\frac{d\gamma}{d\kappa} \ \Delta \kappa \ t_f}{\eta \ R}$$

$$\Rightarrow$$
 Ma \sim 10 2 \sim Ma $_c$

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Outward flow transition

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Outward flow transition

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Outward flow transition

$$v_r = v_{CR} + v_{Ma}$$

H. Hu, and R.G. Larson. Langmuir 21, p.3972-3980 (2005)

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Outward flow transition

$$v_r = v_{CR} + v_{Ma}$$

$$rac{v_{CR}}{v_{Ma}}\sim rac{R^2}{Ma\ h^2}$$

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Outward flow transition

$$egin{aligned} & v_r = v_{CR} + v_{Ma} \ & rac{v_{CR}}{v_{Ma}} \sim rac{R^2}{Ma \ h^2} \ & \Rightarrow v_{CR} \gg v_{Ma} \Leftrightarrow rac{R^2}{h^2} \gg Ma \end{aligned}$$

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Outward flow transition

$$v_r = v_{CR} + v_{Ma}$$

 $rac{v_{CR}}{v_{Ma}} \sim rac{R^2}{Ma \ h^2}$
 $\Rightarrow v_{CR} \gg v_{Ma} \Leftrightarrow rac{R^2}{h^2} \gg Ma$
Motion until $h \sim 10^{-6}$ and $R \approx 10^{-3}$,
 $Ma \sim 10^2$

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Effect of PBS concentration

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Superparamagnetic colloids

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Effect of PBS concentration

Bright field pictures of dried drops :

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Effect of PBS concentration

Conclusion

 Important parameters ? Ionic concentration is one

 Physical mechanisms ? Competition Marangoni-Bénard vs Coffee-Ring

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Conclusion

- Important parameters? Ionic concentration is one
- Physical mechanisms?
 Competition Marangoni-Bénard vs
 Coffee-Ring

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Conclusion

- Important parameters ? Ionic concentration is one
- Physical mechanisms?
 Competition Marangoni-Bénard vs Coffee-Ring

- High PBS keeps Marangoni "honeycomb" patterns after drying
- Could it keep other structures ? e.g. self-assembled superparamagnetic colloids ?

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Prospects

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Superparamagnetic colloids

Thanks for your attention !

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$$\kappa_0 \sim 10^{-2}$$

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$$\kappa_0 \sim 10^{-2}$$

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$$\Delta \kappa \sim \kappa_m - \kappa_0 = \kappa_0 (rac{V_0}{V} - 1) \ \sim \kappa_0 (rac{t_f}{t_f - t} - 1) = \kappa_0 rac{t}{t_f - t} \ \sim 10^{-3}$$

$$\Rightarrow$$
 Ma \sim 10² \sim Ma_c

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Outward flow transition

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Outward flow transition

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Outward flow transition

$$v_r = v_{CR} + v_{Ma}$$

 $v_{Ma} \sim \frac{Ma \ h \ h_0}{R \ t_c}$

R t_f

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Outward flow transition

$$v_r = v_{CR} + v_{Ma}$$

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$$V_{Ma} \sim rac{Ma \ h \ h_0}{R \ t_f}$$

 $V_{CR} \sim rac{2 \ h_0 \ R}{h \ t_f}$

Outward flow transition

 $v_r = v_{CR} + v_{Ma}$

$V_{M_2} \sim$	Ma h h ₀
- ivia	$R t_f$ 2 ho R
$v_{CR} \sim$	$\frac{2}{h} \frac{h_0}{t_f}$
VCR ~	
VMa	Ma h ²

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Outward flow transition

$$v_{r} - v_{CR} + v_{Ma}$$

$$v_{Ma} \sim \frac{Ma \ h \ h_{0}}{R \ t_{f}}$$

$$v_{CR} \sim \frac{2 \ h_{0} \ R}{h \ t_{f}}$$

$$\frac{v_{CR}}{v_{Ma}} \sim \frac{R^{2}}{Ma}$$

$$\Rightarrow v_{CR} \gg v_{Ma} \Leftrightarrow \frac{R^{2}}{h^{2}} \gg Ma$$

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Outward flow transition

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