Physical mechanism of lubrication by lipid layers

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10 mai 2022

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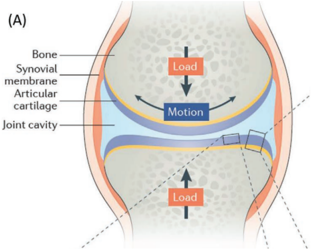
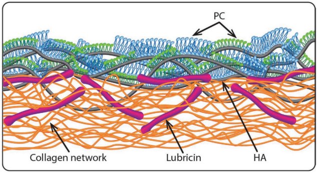
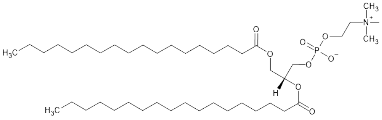
Context : Lubrication in an articulation





- Complex system
- Good lubrication (friction coefficient < 0.01 in a human hip joint with a pressure of 20 atm)
- What is the impact of the phospholipids on the lubrication ?

Lipids



- Hydrophobic tail
- Hydrophilic head

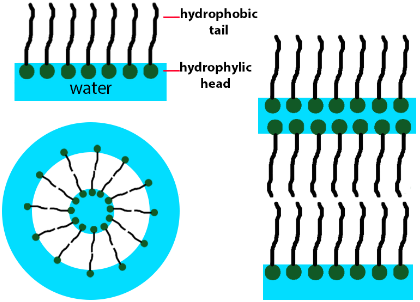


Figure – 3 examples of configurations : monolayer, vesicle, trilayer

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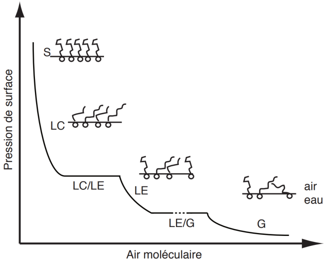
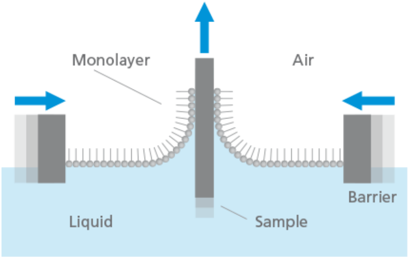
The Langmuir-Blodgett trough

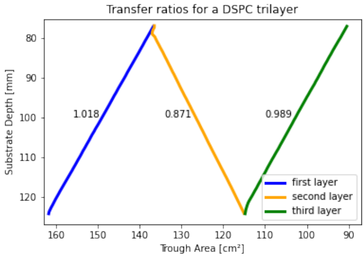


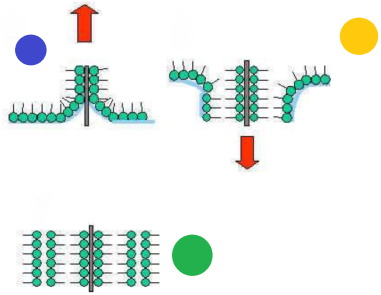


- The surface pressure :

$$\Pi = \gamma_0 - \gamma$$

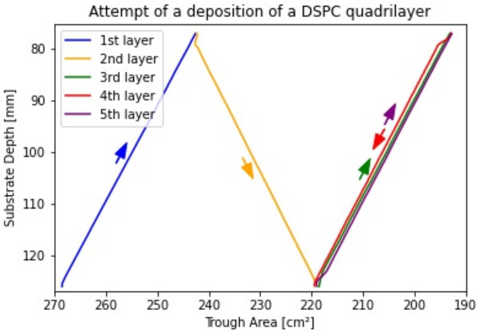
Some depositions





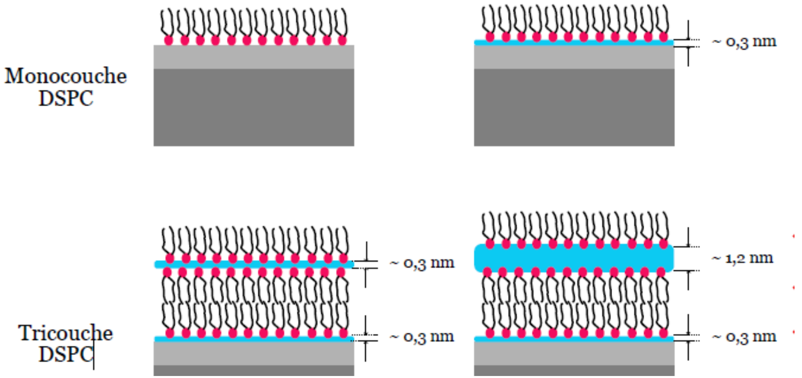
$$\text{Transfer ratio} = \frac{\text{Surface of the trough removed}}{\text{Area of the substrate dipped}}$$

Some depositions



DSPC lipids do not hold more than 3 layers :
4th dip removes the last layer

Comparison of the thickness of water layer with a variation of humidity



Interactions considered :

- Van Der Waals :

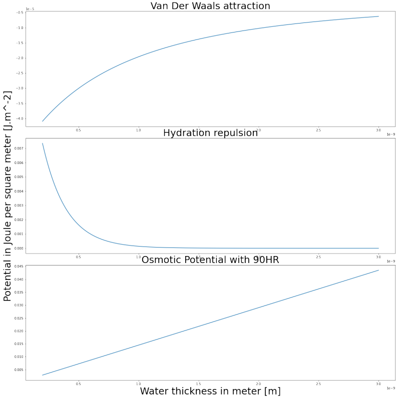
$$U_{VDW}(z) = \frac{H}{12\pi(z + 2z_{head})^2}$$

- Hydration repulsion :

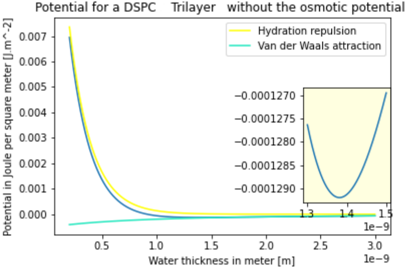
$$U_{hydra}(z) = Phz_h e^{\frac{-z}{z_h}}$$

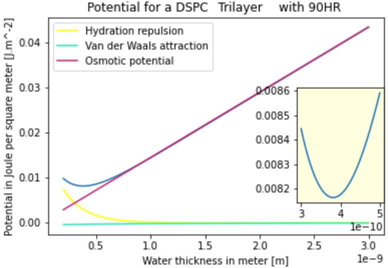
- Osmotic potential :

$$U_{osmo}(z) = -z\frac{RT}{V_m}\log\left(\frac{HR}{100}\right)$$



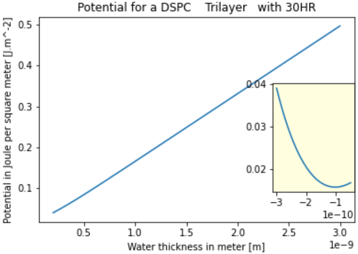
Searching for the thickness of the water layer with the minimum of the potential

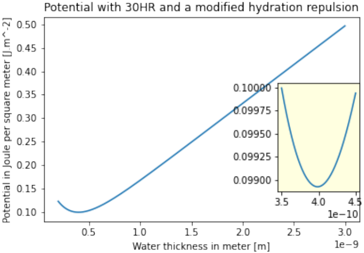




The thickness varies greatly with the variation of the HR

A limit to this model and a simple way to try to correct it





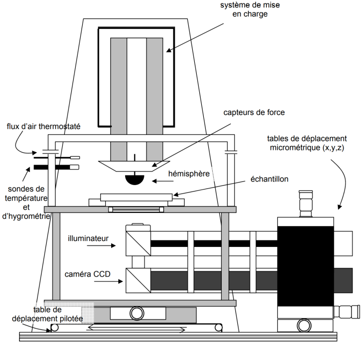
A modification of the hydration repulsion :

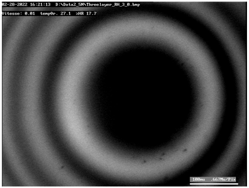
$$Unew_{hydra}(z) = P_h z_h e^{\frac{-z}{z_h}} e^{\frac{z^\star}{z_h}}$$

Micro-Visio Scratch

Sensors are measuring :
the normal force F_n,
and the tangential force F_t.

Contact surface S





Friction measurements

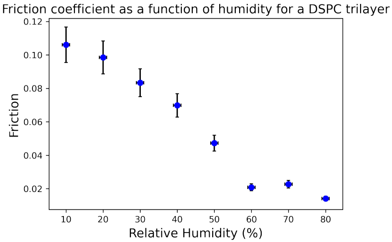
We can measure friction :

$$\mu = \frac{F_t}{F_n}$$

DSPC lipids greatly enhance the lubrication : We rub the glass hemisphere on the sample

Sample :	Glass	Trilayer
Friction μ	0.87	0.08

And we can observe change depending on different properties :

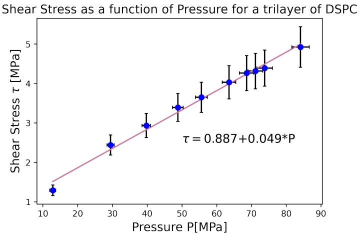


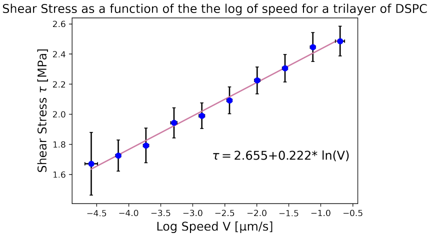
Shear Stress measurements

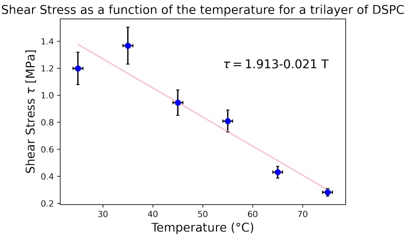
Shear Stress $\tau = \frac{F_t}{S}$

Dependence of τ on :

- Speed
- Pressure
- Temperature







Eyring model (1935)

$$\tau = \tau_0 + \alpha P$$
$$\tau = \tau_0' - \beta T$$
$$\tau = \tau_0'' + \theta \ln V$$

Eyring model :

$$\tau = \frac{kT}{\phi} \ln\left(\frac{V}{V_0}\right) + \frac{1}{\phi}(Q + P\Omega)$$

with Q - activation energy ; ϕ, Ω - activation volumes and P, T, V - pressure, temperature and velocity respectively, τ - shear stress

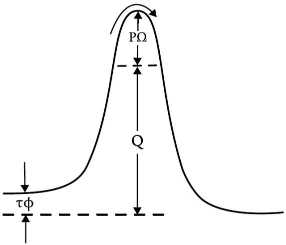


Figure – Potential barrier in the Eyring model

Eyring Model

As we have more equations than variables :

1. $\phi = \frac{kT}{\theta}$
2. $\phi = -\frac{k}{\beta} \ln \left(\frac{V}{V_0} \right)$

$\Omega = \alpha\phi$, $Q = \tau_0''\phi - P\Omega$

Reminder :

$$\tau = \tau_0 + \alpha P$$
$$\tau = \tau_0' - \beta T$$
$$\tau = \tau_0'' + \theta \ln V$$

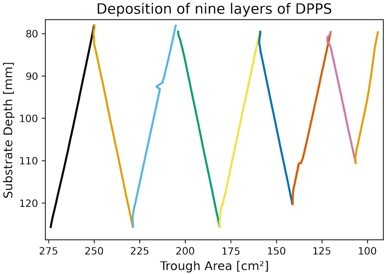
	Method 1	Method 2	Li Fu	T. Mukhina
ϕ [nm^3]	18.63 $\pm$25.47	9.32$\pm$ 1.00	8.6	17$\pm$1
Ω [nm^3]	0.91 $\pm$ 0.31	0.45 $\pm$ 0.07	0.35	0.7$\pm$0.06
Q [kJ]	35.63 $\pm$ 24.84	17.82 $\pm$ 1.91	37	19$\pm$2.4

Conclusion

- We studied DSPC trilayer shear properties with factors - Velocity, Humidity, Pressure and Temperature, replicating experiments performed by Li Fu (PhD) and Tetiana Mukhina (intern).
- We looked at the Eyring model - microscopical model for macroscopic events
- We tried to compute a relation between humidity and the water thickness inbetween layers.

To go further

- We could look at DPPS layers. DPPS lipids have charged heads allowing more layers



- FRAPP (Fluorescence Recovery After Patterned Photobleaching) to better understand molecular vibrations and velocities

- Finding a better model for the thickness of the water layer.