



1. 2D Foam

REPORT

GREECE - Anatolia High School - Name
Hellenic Physical Society I.Y.N.T. - Minsk 2019

Problem to be investigated

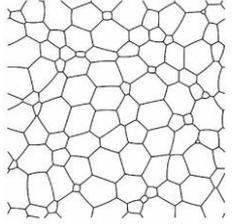
Soap foam enclosed between two glass sheets appears as a network of polygons. Such foams evolve with time, as individual bubbles move and coalesce, and the liquid drains out.

Investigate the **structure** and **evolution** of 2D foams.

Contents

- Introduction
- Theory
- Hypothesis
- Experiment
- Conclusion
- References



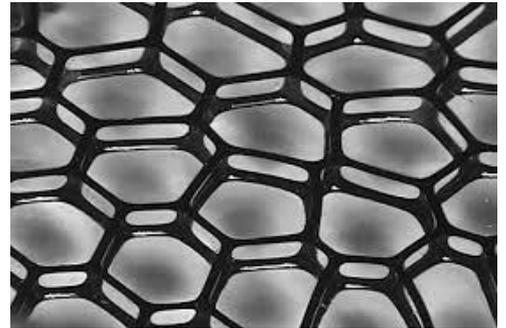


Definition

A two-dimensional foam is a partition of the plane in cells (bubbles) of gas separated by liquid interfaces (films) having a tension line. They are a monolayer of bubbles with cylindrical symmetry.

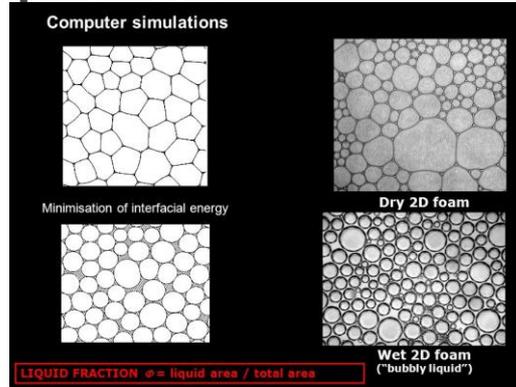
Structure (2D Foam)

- Bubbles separated by some unimportant thickness films.
- The liquid films are lines and the bubbles are polygons.
- Real 2D foams have non negligible thin films between bubbles. The thickness of the films depends on the liquid fraction and on the degree of crushing.

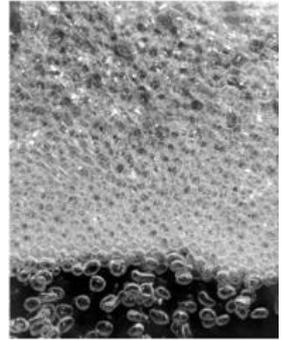


Wet foam vs. Dry foam

In wet foams (where the liquid volume fraction is typically between 10% and 20%) the bubbles are **approximately spherical**.



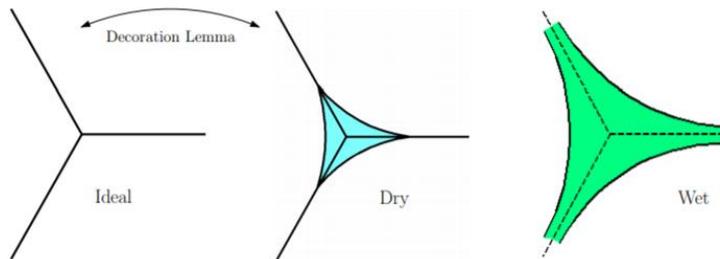
dry foam (top) and wet foam (bottom)



In dry foams (where the volume fraction of liquid is less than 10%), the bubbles are more **polyhedral** in shape.

Wet / Dry / Ideal foam

- **Ideal:** if the liquid stays only in one or zero dimensional subspaces of the plane (respectively the edges and the vertexes) with zero area.
- In other words, the films and the vertexes are respectively lines and points.



Geometry

The geometry of a foam crushed between two solid plates (2D foam) depends essentially on two independent parameters:

- The liquid fraction
- The degree of crushing (ratio of the thickness of the bubble on its diameter). **If compressed**, the bubbles tend to fuse into bigger ones, due to pressure and surface tension.

2D foams through time

- Disappear → **coarsening & film burst.**
- Effects of the **gravity** on the drainage of liquid → **negligible.**
- During their evolution, 2D foams can change their relations of neighbouring between the bubbles.

Experiments



Hypothesis

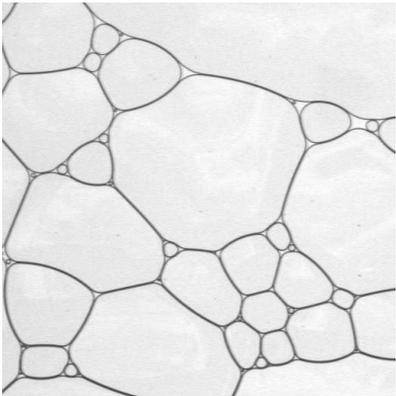
- The permeation of gas from smaller bubbles to larger ones will progressively remove the smallest ones and the foam will continually coarsen, that is, **the average bubble diameter will increase.**
- At the experiment with the wet foam we expect to see bubbles that do not seem like polygons, but as **circles.**
- The vertex will be like a triangle.
- The effects of the gravity on the drainage of liquid will not be **negligible**, because the sample will be in a vertical position.

Instruments

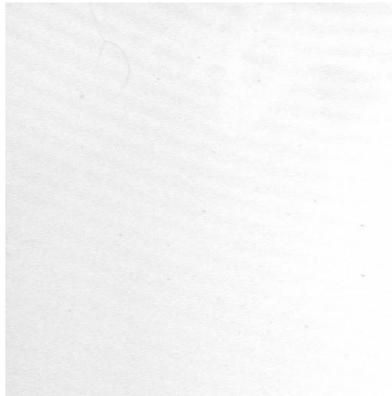


Experiment Wet foam (Vertical)

We took photos of the experiment each minute. We saw that the wet foam disappeared of our view after 21 minutes.



0 min

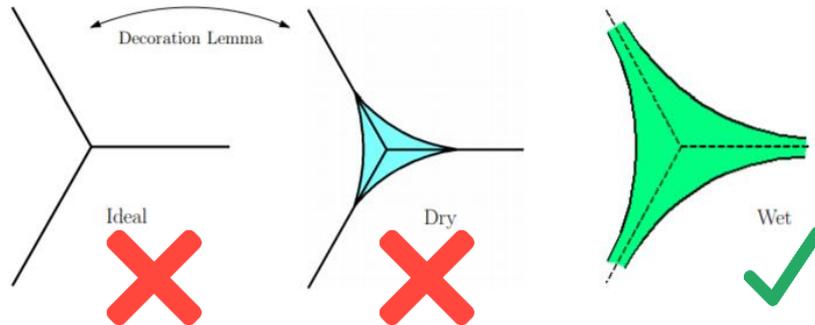
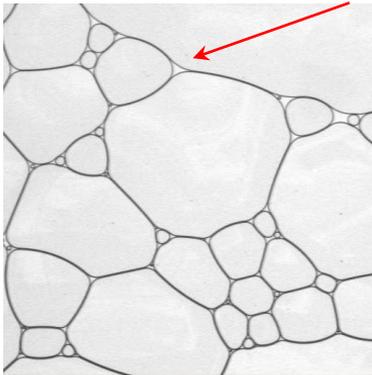


21nd min

Wet Foam

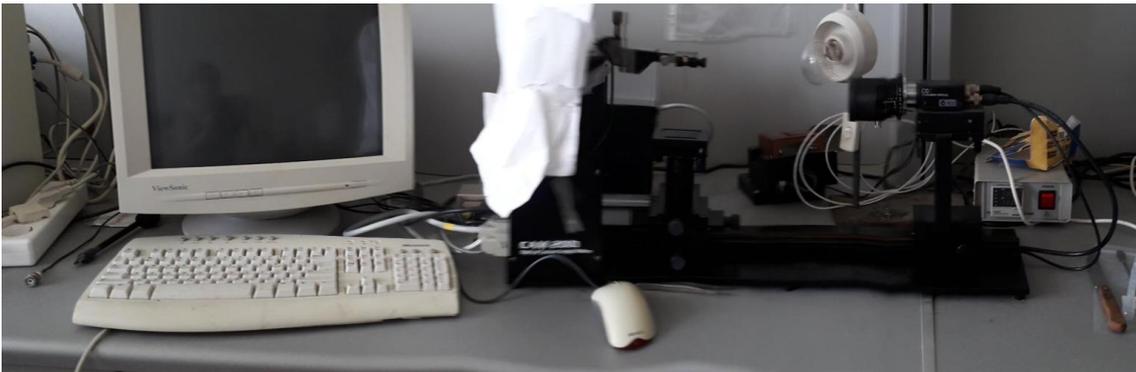
The foam was wet because:

- The liquid bubbles were approximately spherical
- There was a triangle (vertex) when the bubbles were formed.



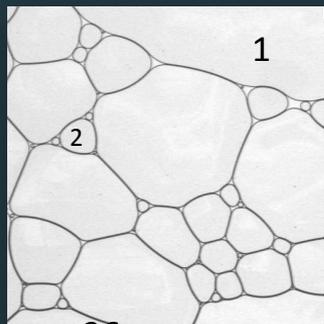
Vertical position

- **Acceleration of gravity.**
- Our sample was in a vertical position *droplets* were formed. The gravity acceleration \vec{w} was not orthogonal to the plane, so the effects of it on the drainage of liquid were **not negligible**.

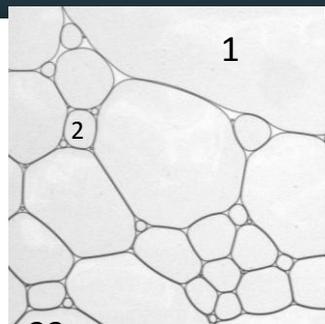


Evolution of the foam throughout time

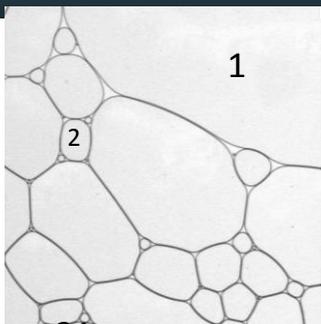
- Through time we saw that the **wet foam** transformed into an **ideal foam**.
- The triangle (vertex) disappeared after the **4th** minute.
- Throughout time we saw that at the top part of our sample the foam was dry and at the bottom part of the sample the foam was wet, because of **gravity**.



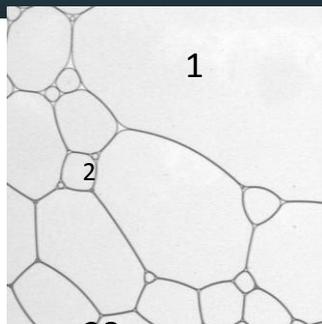
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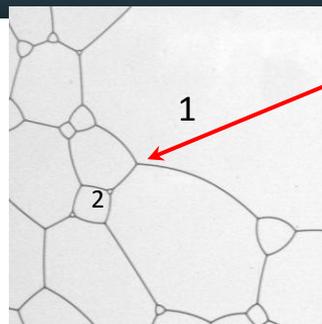
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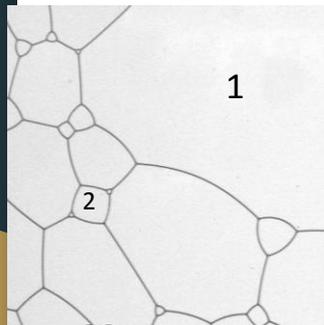


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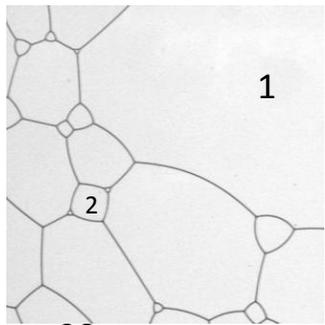


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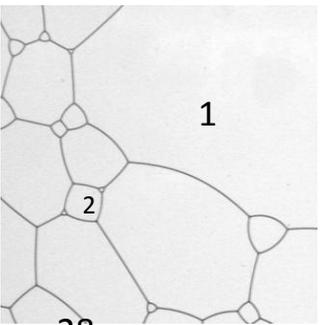
Ideal foam
4th min



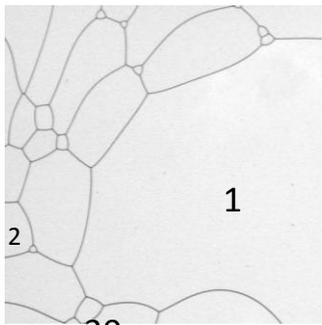
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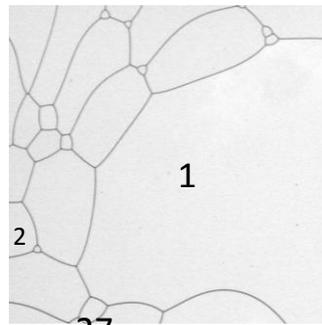
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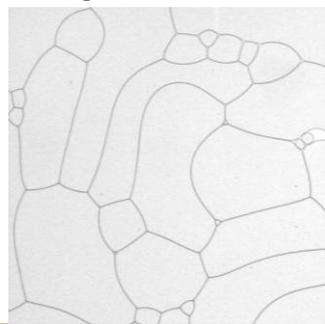
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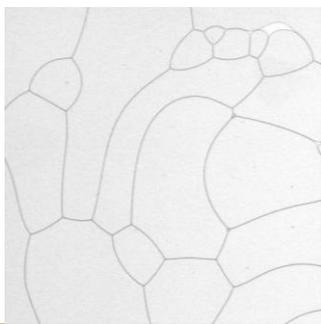
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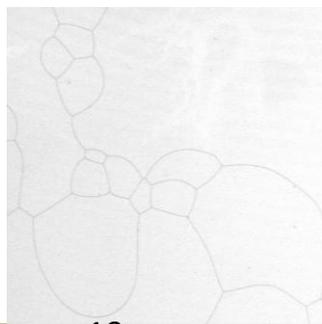
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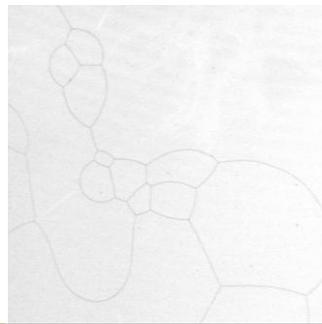
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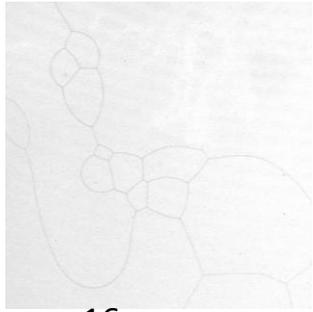


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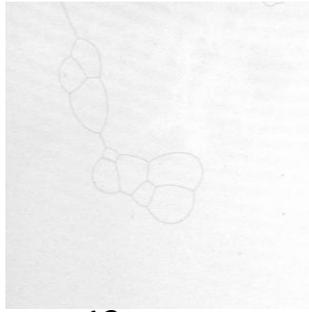


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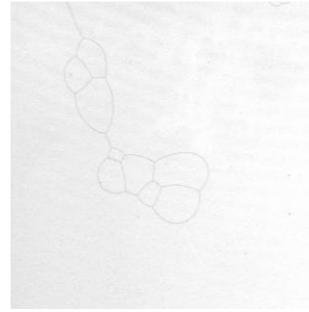
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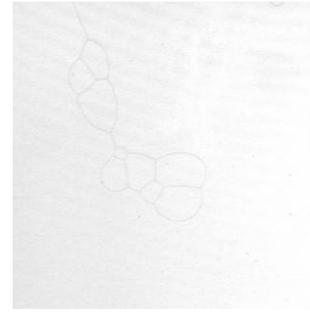
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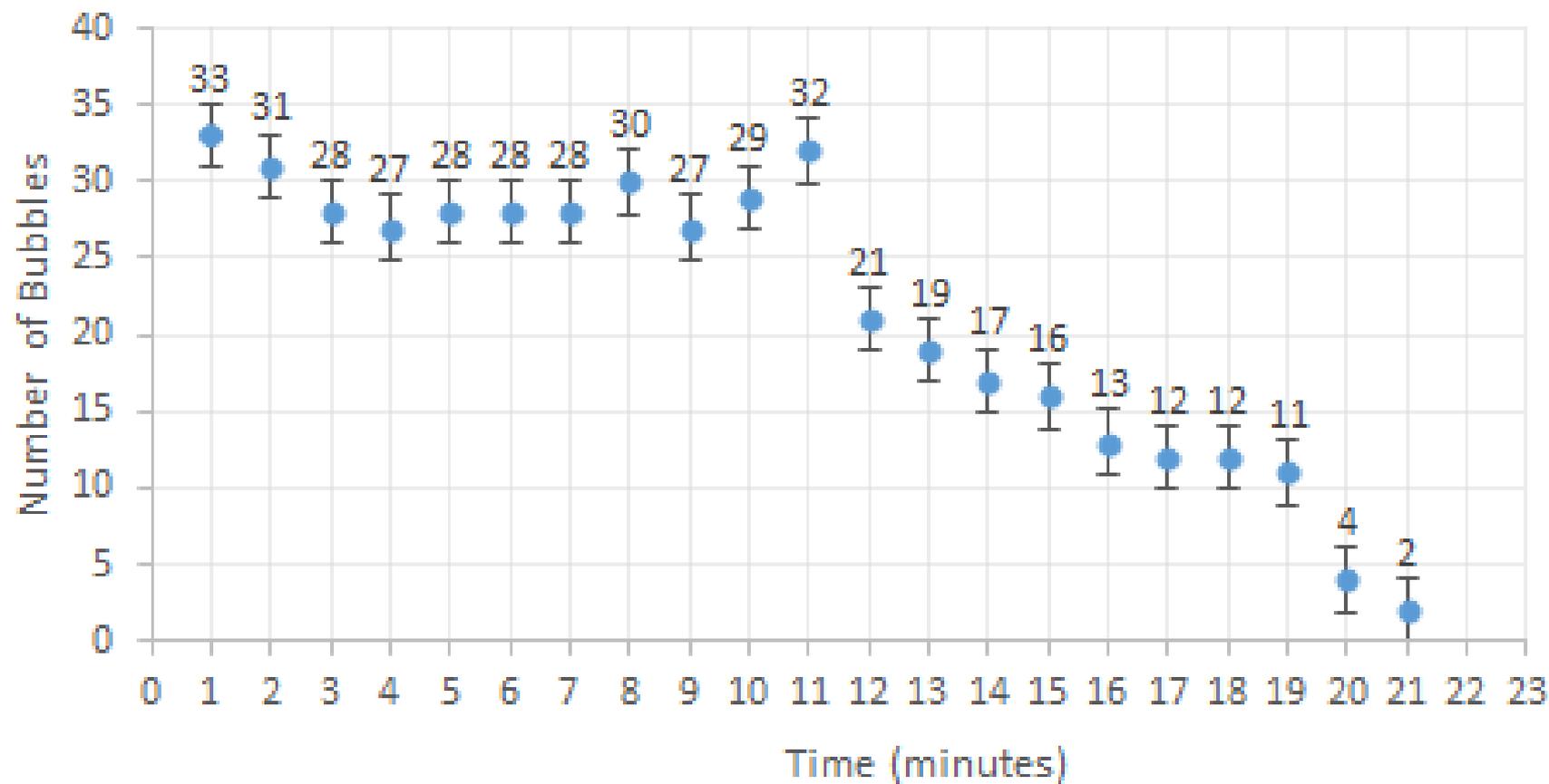
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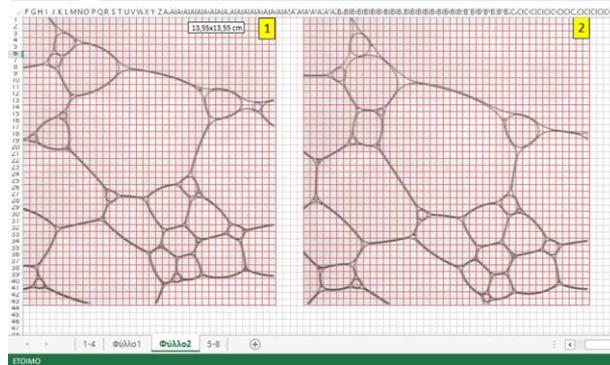
Here we see the evolution of the wet foam. We were taking photos every minute until the foam disappeared.

Number of Bubbles VS Time

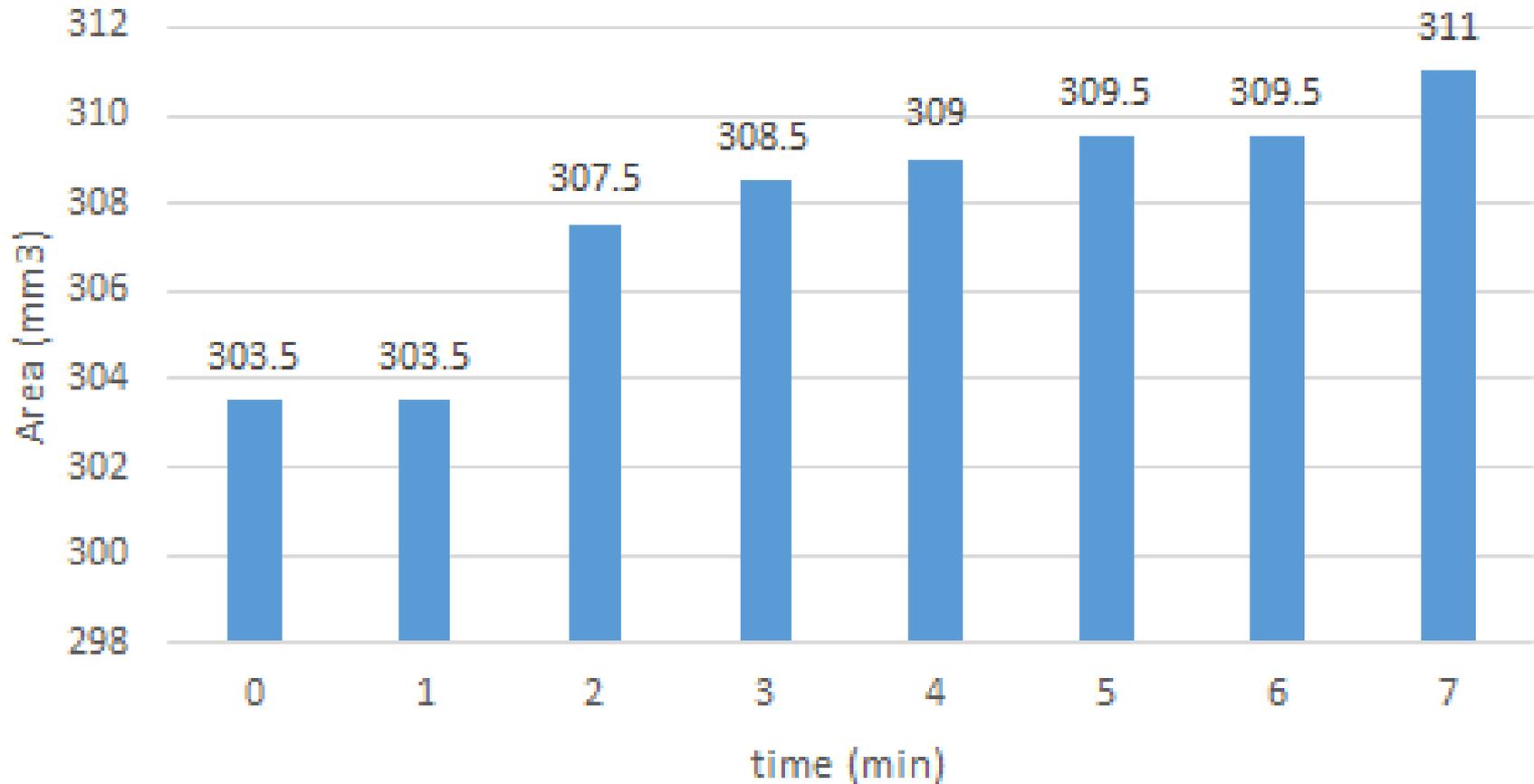


Measuring bubble Area

- We used “microsoft excel” for the millimetre paper
- We counted the millimetre boxes that fit in the bubbles.
- Thus, we measured the area of the bubbles, (mm^3)



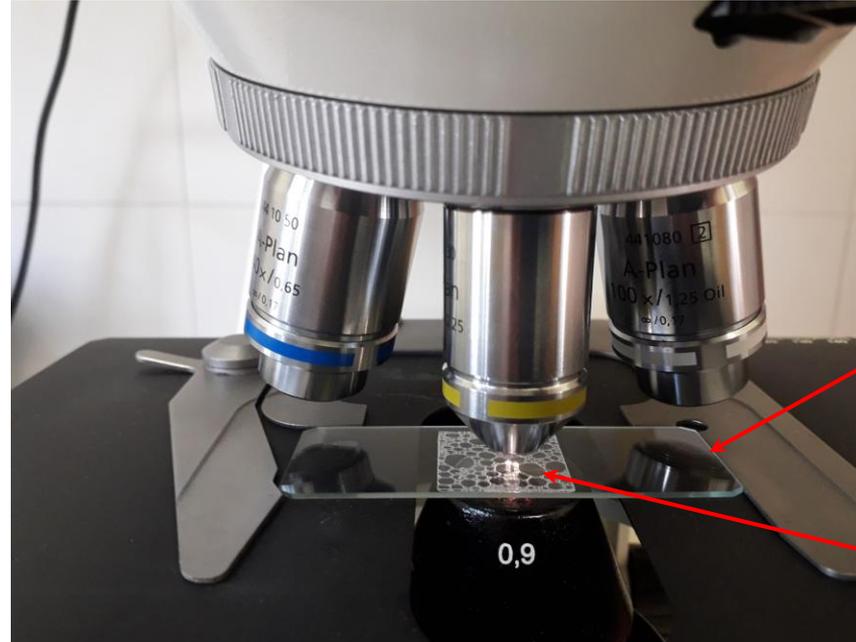
Area of bubble per minute



Hypothesis

1. The permeation of gas from smaller bubbles to larger ones will progressively remove the smallest ones and the foam will continually coarsen, that is, **the average bubble diameter will increase.**
2. At the experiment with the wet foam we expect to see bubbles that do not seem like polygons, but as circles.
3. The vertex will be like a triangle.
4. The effects of the gravity on the drainage of liquid will be **negligible**, because the sample will be in a horizontal position.

Instruments

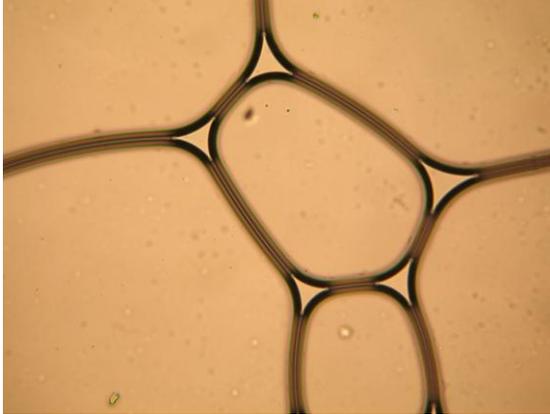


glass sheets

Soap

Experiment wet foam (horizontally)

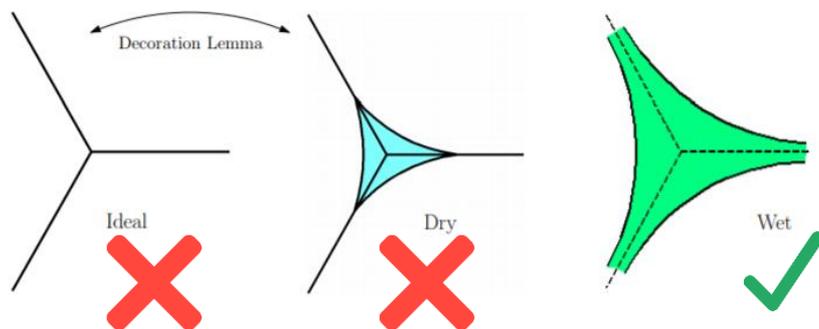
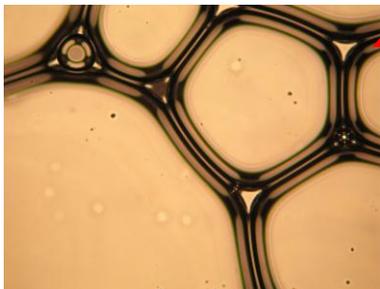
We were taking photos of the sample every minute for five minutes.



Wet Foam

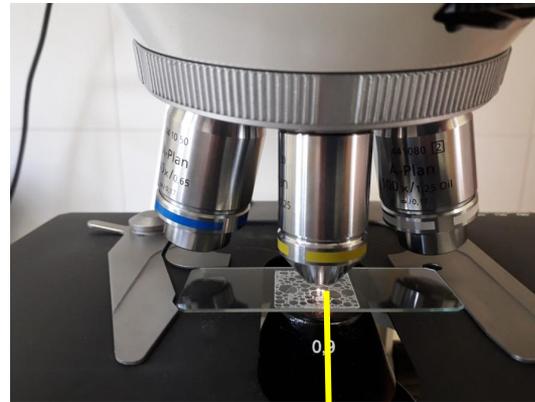
The foam was wet because:

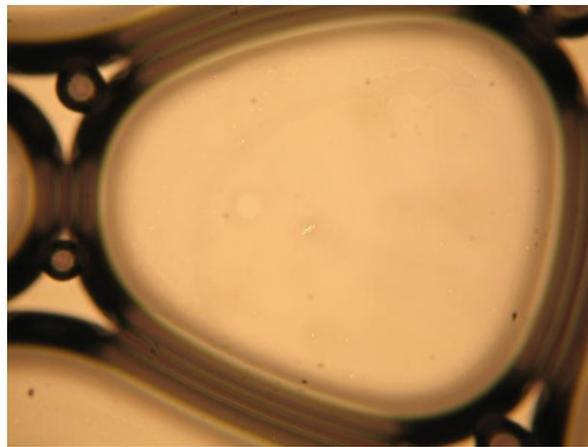
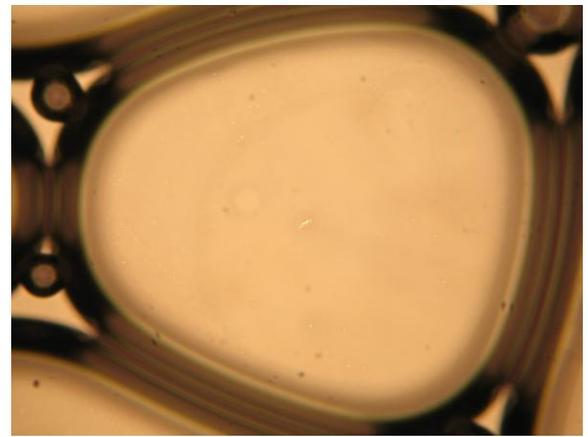
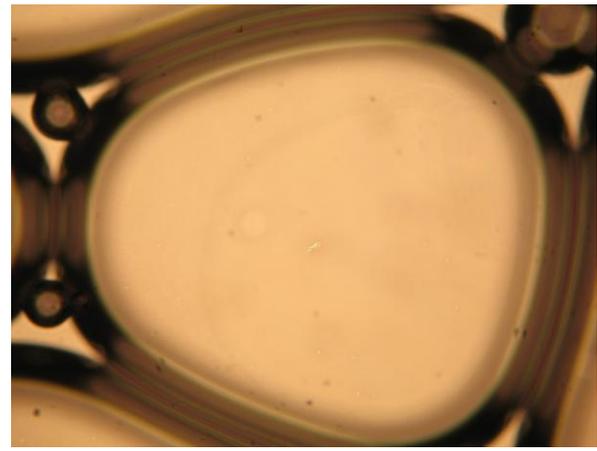
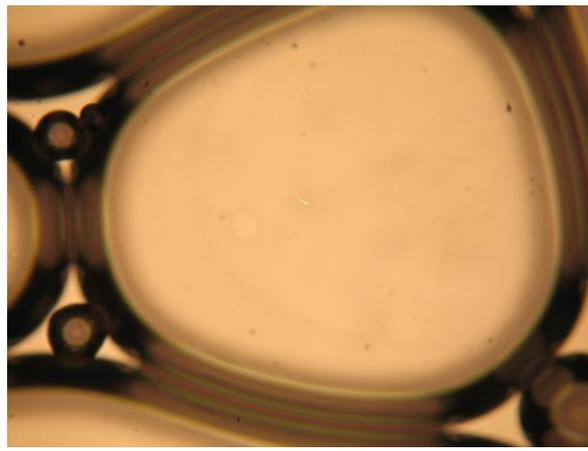
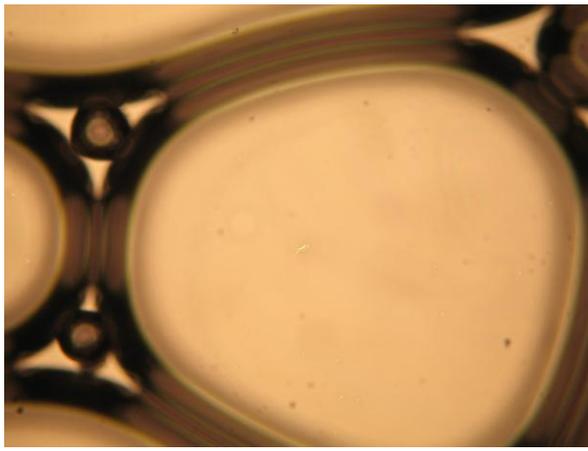
- The liquid bubbles were approximately spherical
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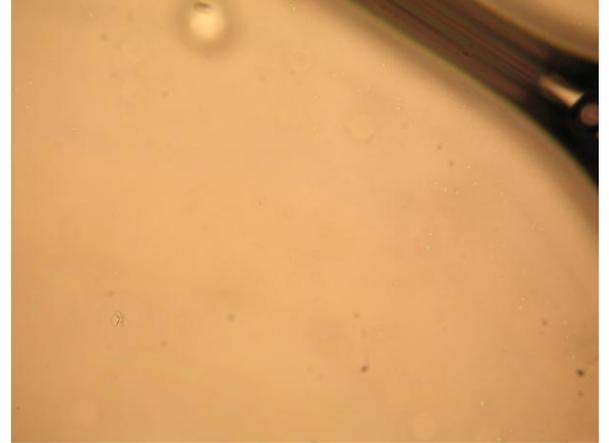
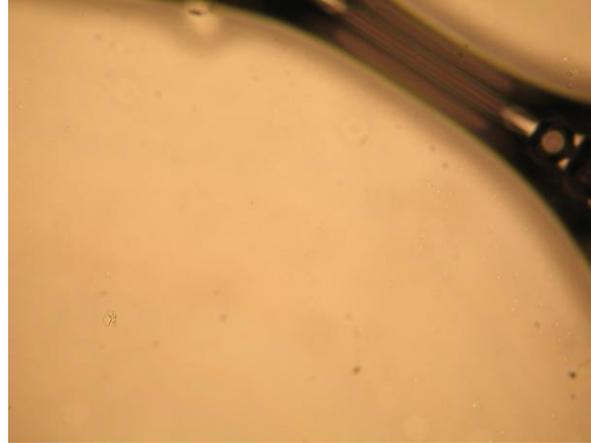
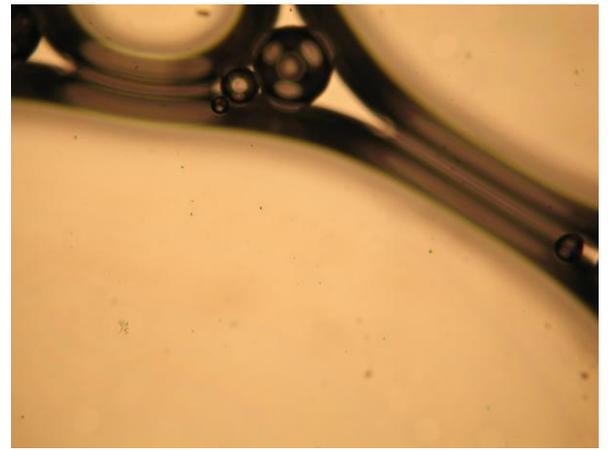


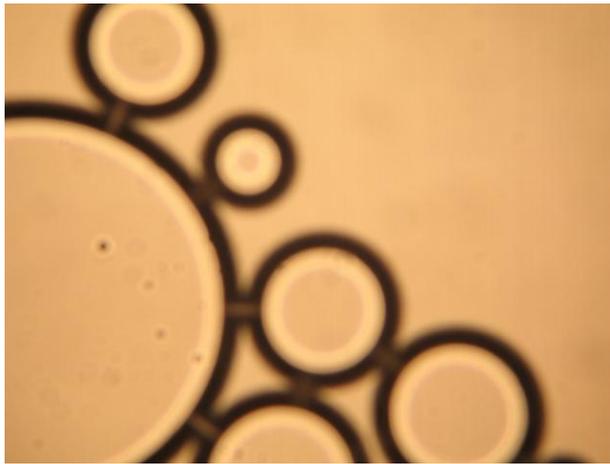
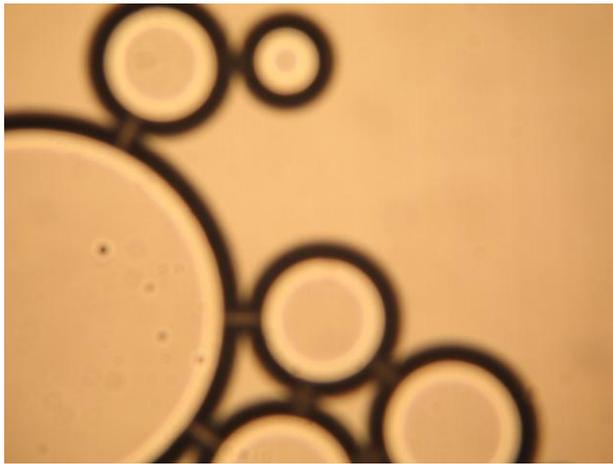
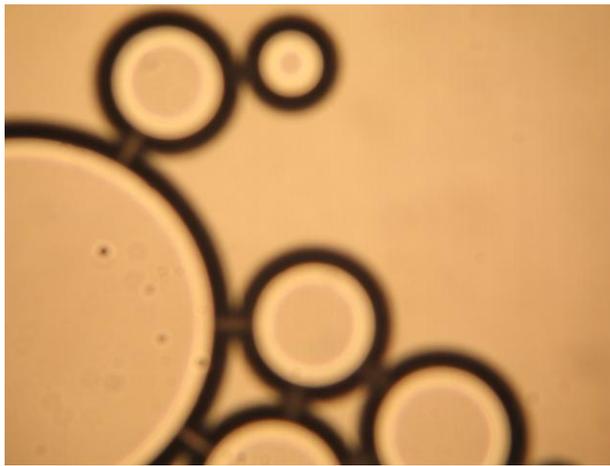
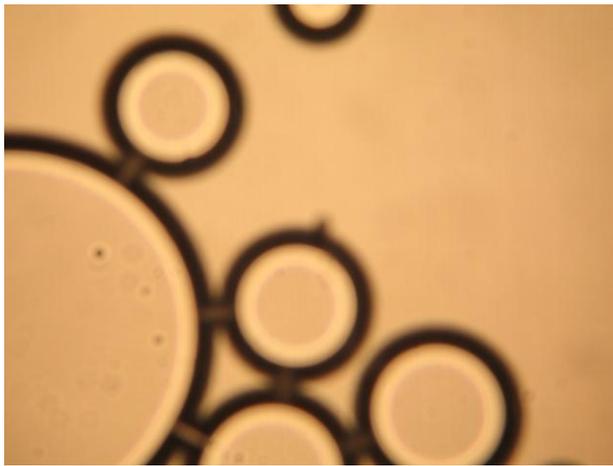
Horizontal position

- Gravity was **orthogonal** to the plane of the foam, in two dimensions.
- The effects of the gravity on the drainage of liquid were negligible.

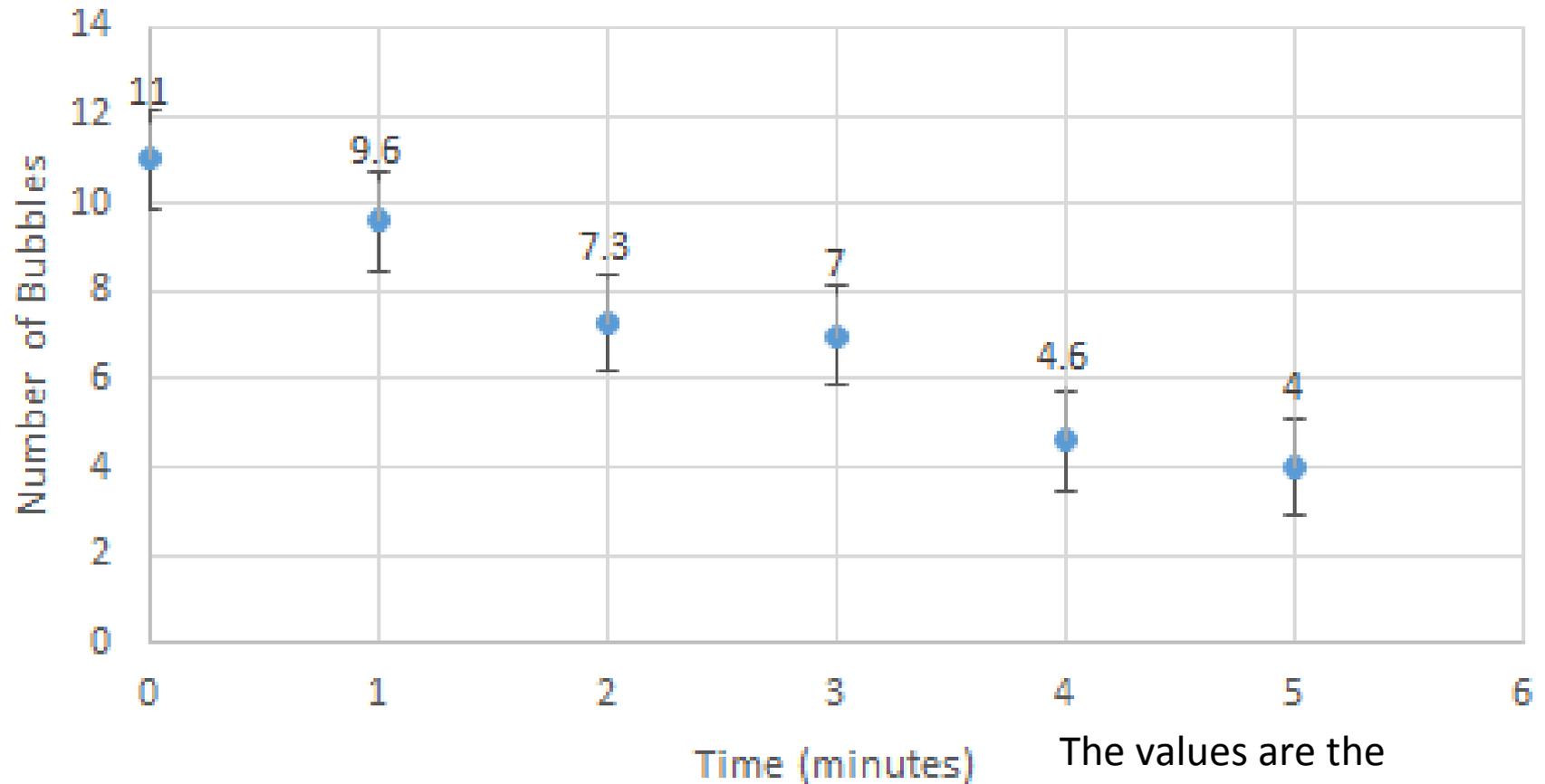








Number of Bubbles Vs. Time



The values are the means of 3 samples

Conclusions

1. The Average Bubble diameter increased.
2. The bubbles that we saw were not polygons, but circles.
3. The vertex was like a triangle, so the foam was wet.
4. The effects of the gravity on the drainage of liquid was **not** negligible, because the sample was in a vertical position. (1st experiment)
5. The effects of the gravity on the drainage of liquid was **negligible**, because the sample was in a horizontal position. (2nd experiment)

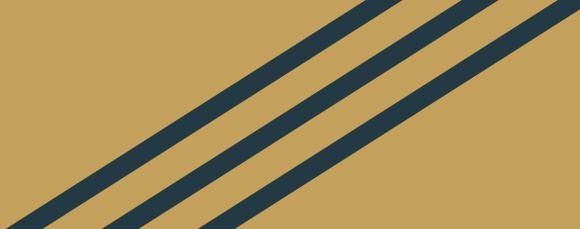
References

- https://www.researchgate.net/publication/312531146_Theory_on_2D_Foams
- https://www.youtube.com/watch?v=RXkYjL_7jME
- https://petrowiki.org/Foam_properties
- <https://tel.archives-ouvertes.fr/tel-00010304/document>
- <http://www.msc.univ-paris-diderot.fr/~cgay/homepage/doku.php?id=publications:2009bulimia>
- <https://en.m.wikipedia.org/wiki/Volume>
- <https://www.sciencedirect.com/science/article/pii/S0927775707001586>

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Thank You For Your Attention!



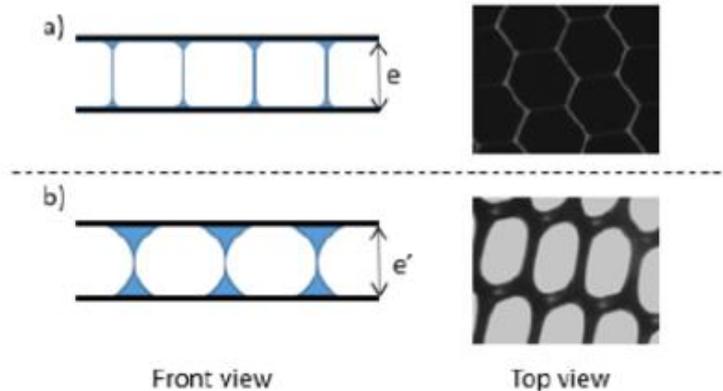


APPENDIX



Example

Figure a, the foam is trapped between two plates apart of e . If e decreases or if Φ increases, the films adhering to the plate grow and the bubbles appear smaller and distant (figure b)



Theoretical model

$$m(n) = 6 - a + \frac{6a + \mu_2}{n}$$

Where,

- **m(n)** the average number of sides of cells which are neighbours of n-sided cells,
- **μ_2** the second moment of the distribution of the number of sides and the parameter a exhibits some variation among the many natural cellular patterns that show the correlation

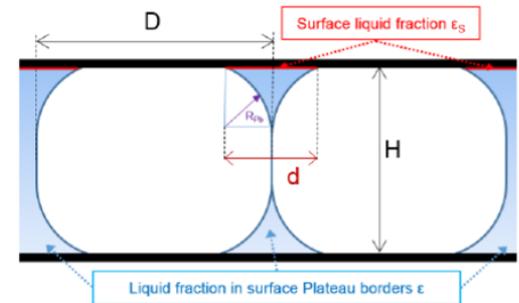
Mathematics

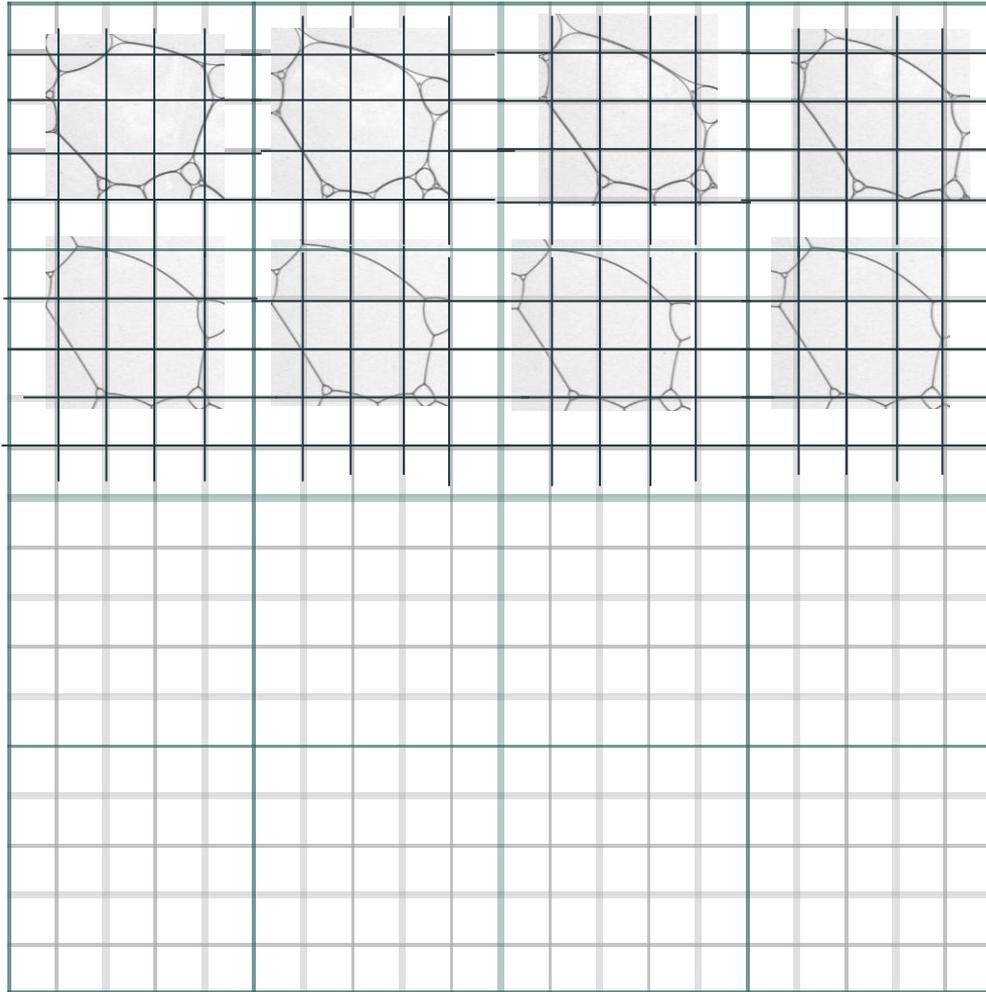
The liquid content in the surface Plateau border network ϵ_S can be naturally determined as a ratio of the surface of the surface Plateau borders to the total surface of the foam.

G: the ratio of the bubble area to the area of a circumscribed regular hexagon. G can be expressed as a function of d, D and to the wetted fraction at the wall ϵ_S :

$$G = \frac{1 - \epsilon_S}{\left(1 - \frac{d}{D}\right)^2}$$

d: the gap between the 2 plates
D: Surface Plateau border.



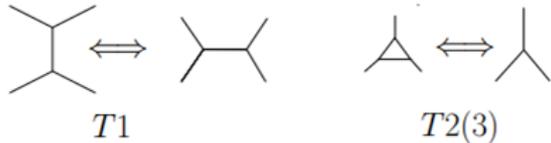


Topological changes

The phenomena mentioned before are called *Topological changes*.

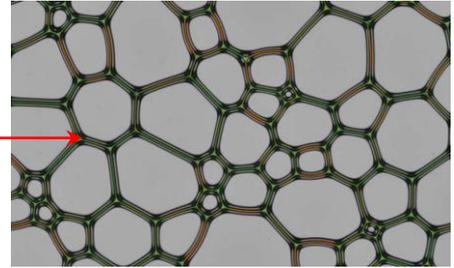
T1. It doesn't change the number of bubbles, it changes the neighbourhoods.

T2. Is the disappearance of a bubble \longrightarrow number of bubbles changes.



Plateau's laws

Plateau Border

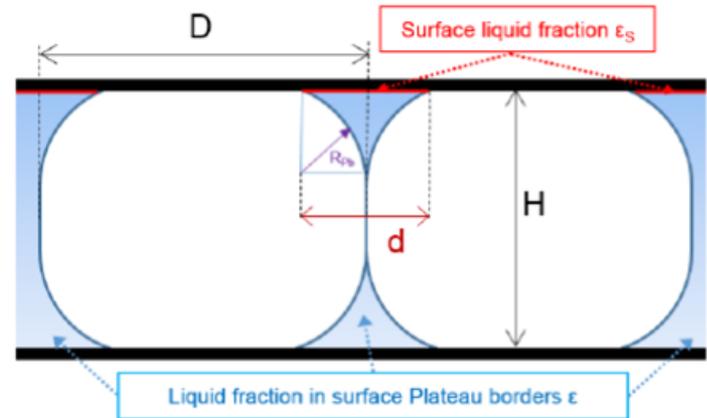


Plateau's laws describe the shape and configuration of soap films as follows:

1. Soap films are made of entire (unbroken) smooth surfaces.
2. The **mean curvature** of a portion of a soap film is everywhere constant on any point on the same piece of soap film.
3. Soap films always meet in threes along an edge called a **Plateau border**, and they do so at an angle of $\arccos(-\frac{1}{2}) = 120^\circ$.
4. These Plateau borders meet in fours at a vertex, and they do so at an angle of $\arccos(-\frac{1}{3}) \approx 109.47^\circ$

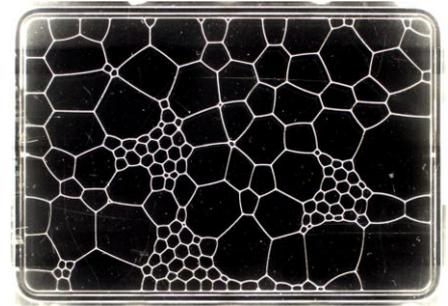
Node or Vertex

A junction of 3 surface Plateau Borders and one Plateau border in is called a node or a vertex. The case of two separated surface Plateau borders networks is characterized by a radius of curvature R_{pb} much smaller than the gap between the plates.



Geometry

The surface networks can be considered as completely independent. Viewed from above, only the surface Plateau borders are visible: they form two identical hexagonal honey-comb networks.



Geometry

- The structure of 2D foam can be simply described in the case of ordered monodisperse foam in equilibrium. Each monodisperse bubble is surrounded by 6 neighbors.
- 6 Plateau borders
- 12 Surface Plateau borders
- 6 films separating bubbles
- 2 wetting films covering

