Ice clock

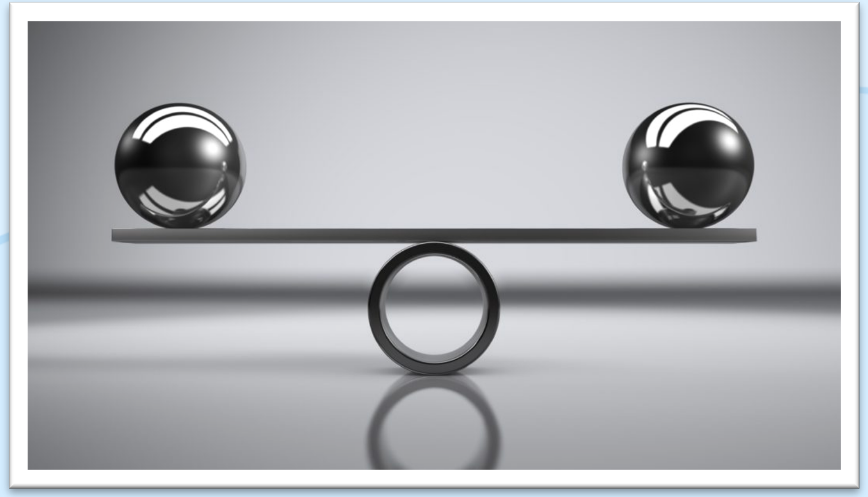
International Physicists' Tournament

The experiment

The underlying physics: a matter of density

Specific masses:

- Ice: 0,917 $\pm 0{,}001\ kg/L$
- Vegetable oil: 0,920 $\pm 0{,}003\ kg/L$ at 20 $°C$
- Baby oil: 0,83 $\pm 0{,}01\ kg/L$
- Water: 0,997 $\pm 0{,}001\ kg/L$ at 20 $°C$



General outline of the problem

- Thermodynamics and diffusion
- Surface tension
- Caluculation of the longevity and precision of the apparatus
- Optimization ideas inspired by the above discussion
- Further thoughts and experiments

Thermodynamics of the melting process

Assumptions and modelization:

- $\lambda_{ice} \gg \lambda_{water}$
- $T_{ice} = T_{water} = 0$
- $d_{oil} \gg d_{temperature}$
- Temperature profile constant in time

Thermodynamics of the melting process

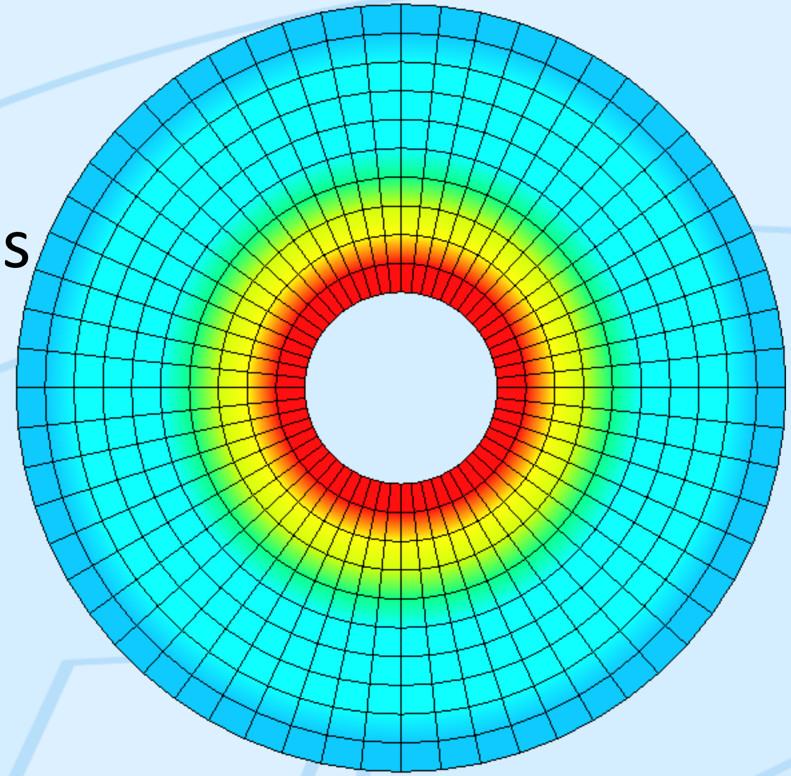
Qualitative discussion:

- Thermal flow proportional to surface of ice
- The ice melts because of thermal flow
- One expects a differential equation with respect to time

Melting equations

- Fourier's law: $\frac{d\phi}{dt} = -\lambda\overrightarrow{grad}\phi$
- Energy conservation between concentric spheres

- $T(r;t) = \frac{(T_f - T_0)R(t)}{r} + T_0$
- Doesen't depend upon thermal conductivity !
- Thermodynamics: $\frac{dm}{dt} = -\frac{dq}{dt}\frac{1}{c_{fus}}$



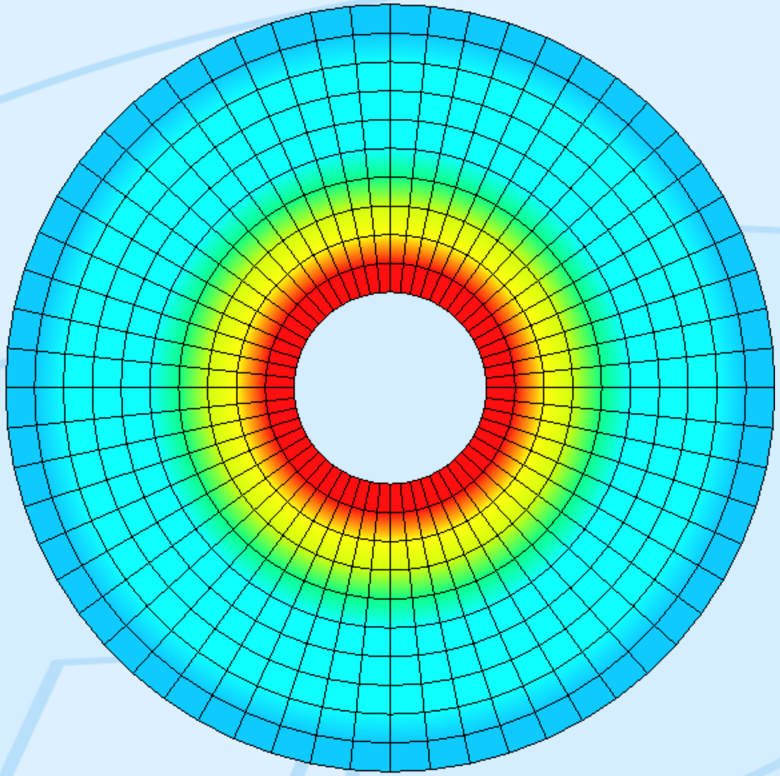
Temperature profile simulation around a spherical ice cube

Melting equations conclusion

- Melting time: $t_f = \frac{R_0^2 c_{fus} \rho}{2\lambda(T_0 - T_f)}$

- $\frac{dV(t)}{dt} = \frac{4\pi\lambda\Delta T}{c_{fus}} \sqrt{R_0^2 - \frac{2\lambda\Delta T}{c_{fus}\rho} t}$

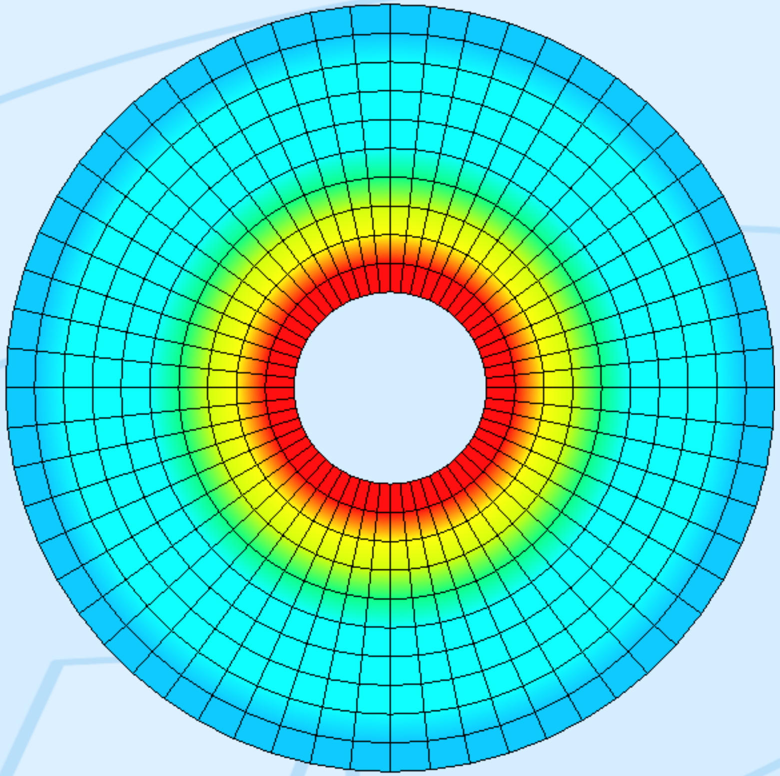
- Flow nearly constant if $R(t)$ varies only slightly
- Characteristic distance: $d = \mathrm{R}_0$



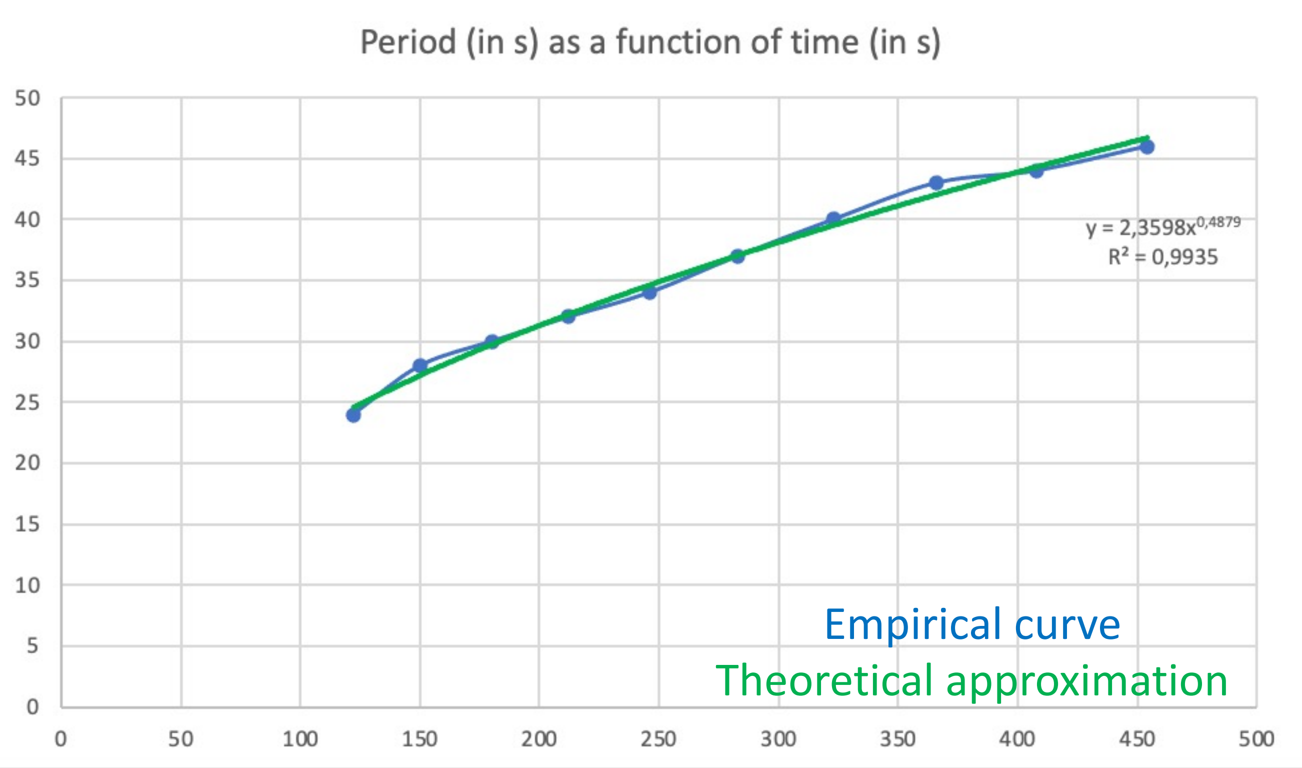
Numerical results

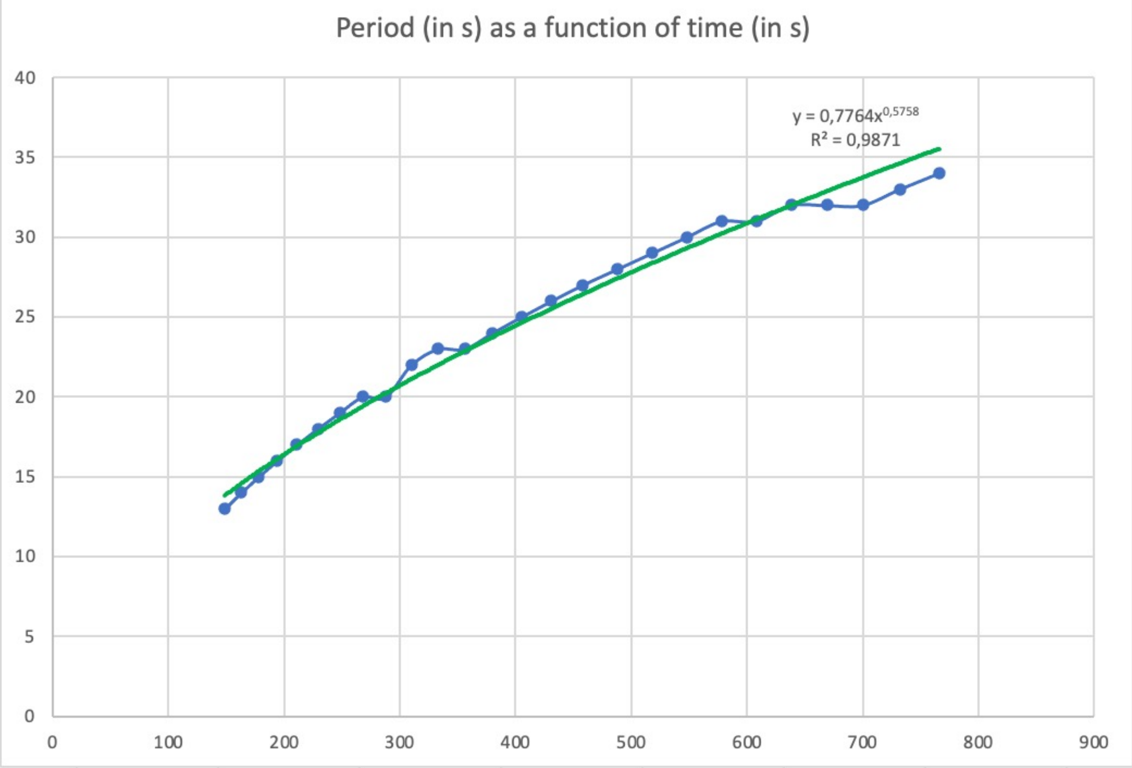
- $R_0 \approx 2\ cm$

- Melting time: $t_f \approx 30\ minutes$
- $\frac{dV}{dt} \approx 0.1\ mL/s$



Comparison to experiment





The shape and size of drops

Assumptions and modelization:

- Shape only determined by capillarity forces –gravity is neglected as far as the shape is concerned-
- The ice, water and oil are homogenious

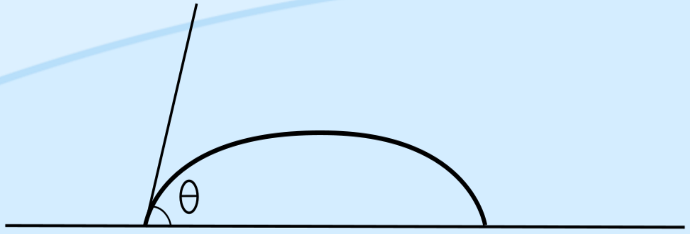
The shape and size of drops

Qualitative discussion:

- Different magnitudes of tensions
- Adhesion forces
- Gravity
- Let’s not forget Archimedes

The shape of drops, equations

- The angle is given by: $\cos(\theta) = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}$
- Numerically, $\theta \approx 90°$



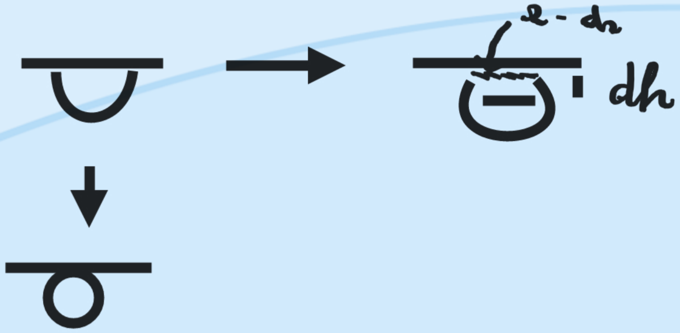
- Round drops are an honest approximation. Experimentally valid.
- Drops flow to an edge because of gravity.

When do the drops fall?

- $F = 2\pi r\,(\gamma_{OI} - \gamma_{WI})$

- $V_{fall} = \frac{4}{3}\pi\left(\frac{\gamma_{OI}-\gamma_{WI}}{\rho' g}\right)^{3/2}$

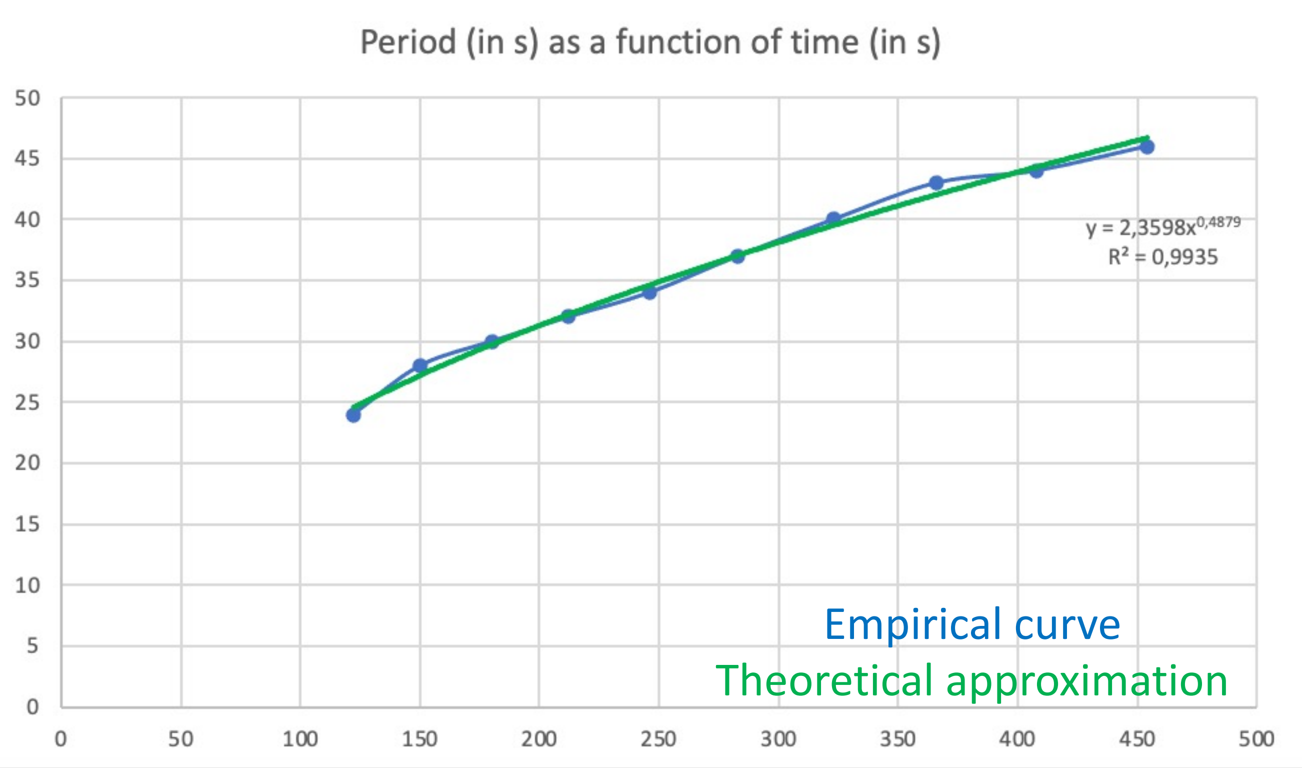
- Close result with an energetical approach !

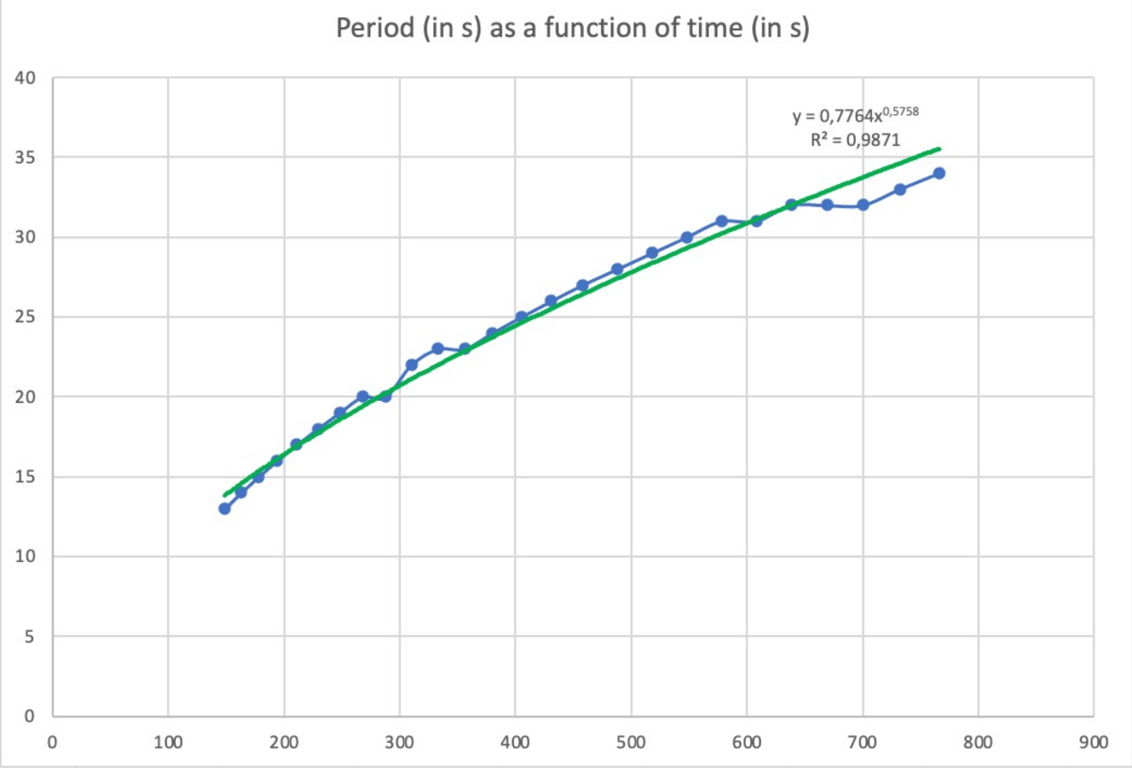


Theoretical results

- $V_{fall} \approx 0{,}2\ mL$
- $\frac{dV}{dt} \approx 0{,}01\ mL/s$

Comparison to experiment





Optimization ideas

- Bigger ice cubes
- Problem: need to increase the size of the container !

Optimization ideas

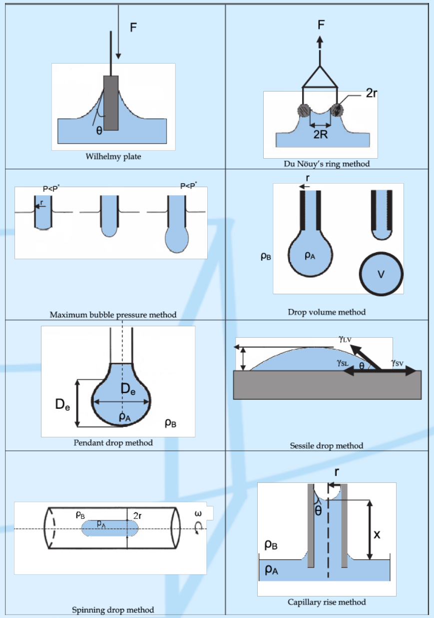
- Reduce temperature
- Keep the temperature constant
- The shape doesn’t seem to change much (droplets small compared to ice cube)

Another version of the experiment

- A more homogenous liquid: only vegetable oil !
- Problem: need to fine-tune the temperature

Further thoughts and experiments

- Measure precisely the surface tensions in order to enhance the theoretical calculations
- Different methods: ring, drop shape, stalagmometer…
- Measure precisely the densities as functions of temperature
- Density of the ice with respect to time (air bubbles)



Credits

- Irene Mauro (my 13-year-old sister) who designed the background
- My friends, for their precious advice
- My parents for their patience while I flooded the kitchen with oil