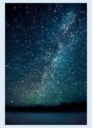
A Bubble's Odyssey

Or what is the fate of a bubble in a carbonated beverage?

Jonas Miguet

Outlook

- General considerations 
- Birth 
- Growth 
- Detachment 
- Flying to the sky 
- On the edge 
- Bursting through the sky 
- Outcome 

Supersaturation

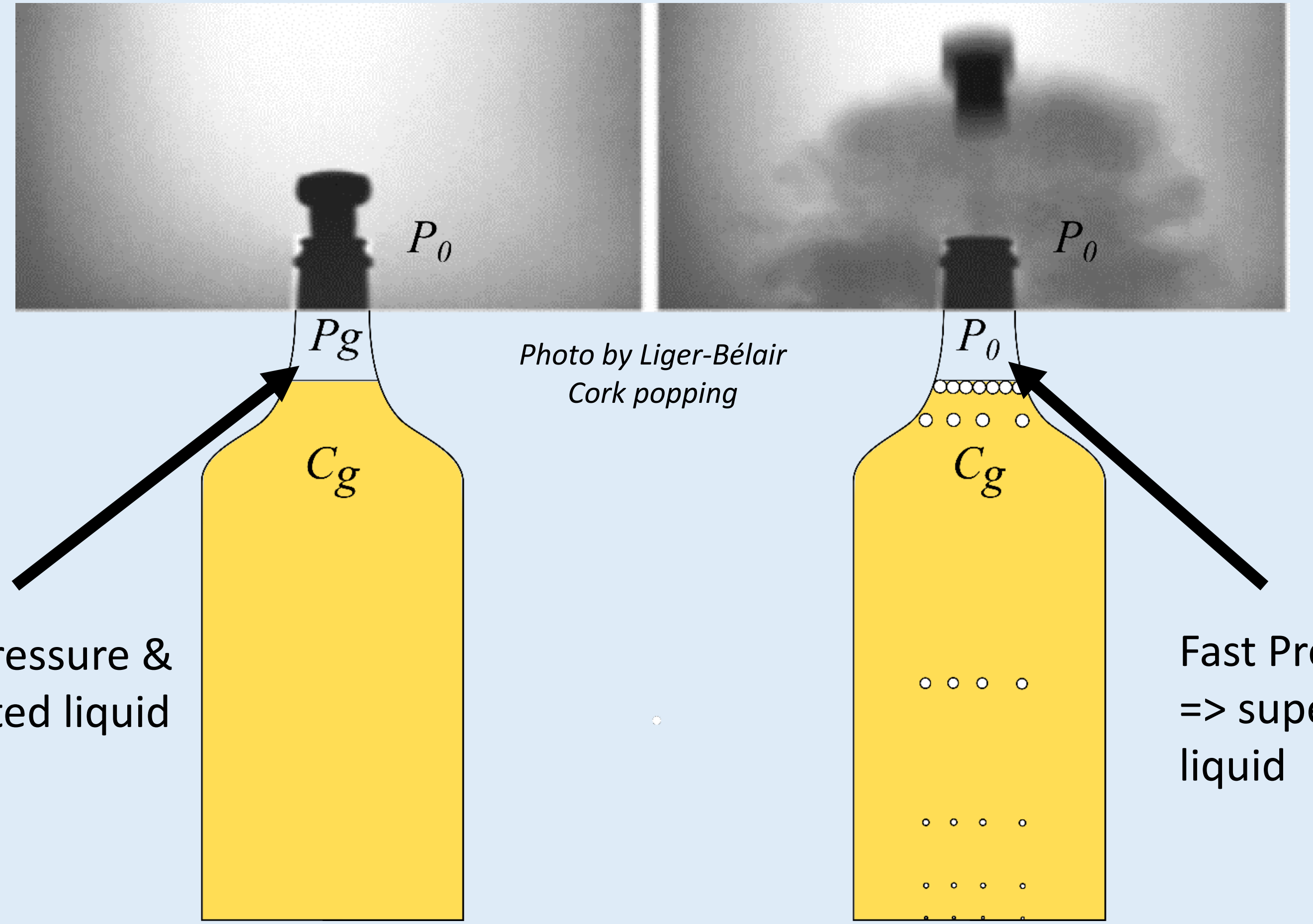


Photo by Liger-Bélair
Cork popping

High pressure &
Saturated liquid

Fast Pressure drop
=> supersaturated
liquid

Parameter $S = \frac{C_g}{C_0} - 1$

C_g : actual concentration

C_0 : saturation concentration

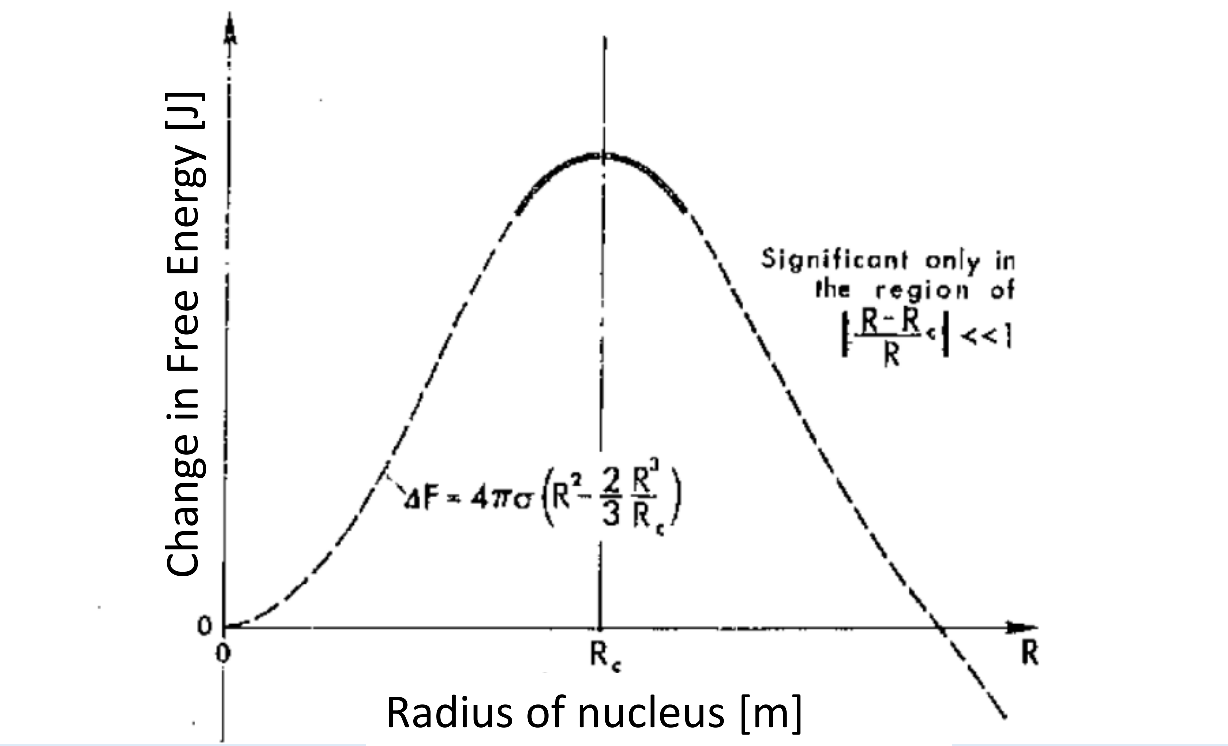
Henri's equilibrium :
$P_g = Kh(T) * C_g$

General
Considerations

Condition for a bubble to grow

- Creation of interface => energy cost
- Volumic extension ie work creation => energy gain

Metastable equilibrium



Ward et al., J. Basic Engin., 1970

Existence of a critical radius

$R_c \sim \frac{2\gamma}{P_0 S} \sim 1\mu m$

γ : surface tension [$N.m^{-1}$]

=>Supersaturation is necessary but not sufficient for the spontaneous occurrence of a bubble
(Therefore water does not boil per se at 100°C…)

=>In practice, nucleation sites pre-exist

General Considerations

Birth

Formation of nucleation sites

Asperities

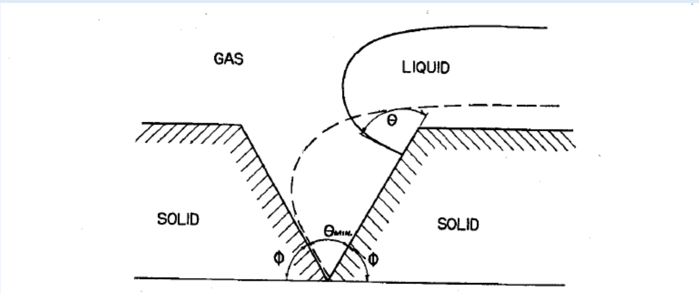


Fig. 1. Conditions for the entrapment of gas in the advance of a semiinfinite liquid sheet across a groove.

Bankoff, 1958

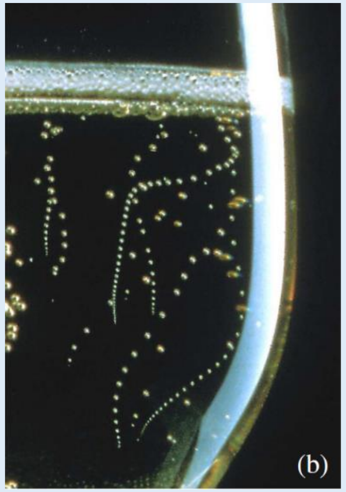
Condition for gas entrapment :

$$\underbrace{180 - 2\Phi}_{\text{Cone angle}} < \underbrace{\theta}_{\text{Advancing contact angle}}$$

If this condition is met, a gas pocket can be formed

Impurities/Seeds

More generally met in your glasses (fibers)



Photos by Liger-Bélair

Cellulose fiber adsorbed on a glass wall

« Flying » cellulose fiber, serving as nucleation site

Turbulent eddies can also serve as nucleation sites =>lean your glass to avoid foam occurence/gas losses

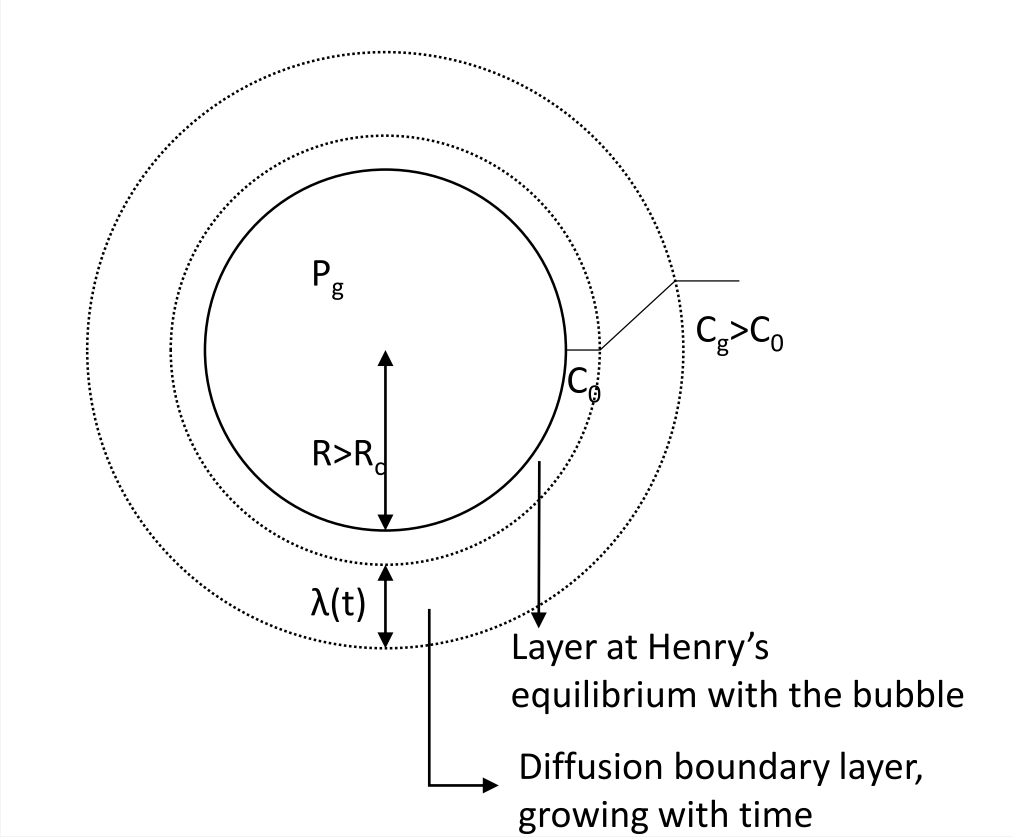
Growth

Determines the rate of bubble production for a given nucleation site and the size of bubbles at the air/liquid interface

<u>Growth rate is proportionnal to</u>:

$t^{1/2}$	if the liquid is at rest
t	otherwise

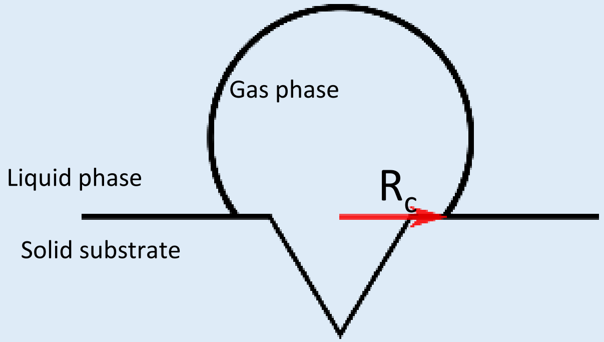
Was shown to be α t in the case of carbonated water in a glass



Detatchment

The radius of the detaching bubble results from a balance between gravity and Gas-Liquid interfacial tension.

$$R_b = \left(\frac{3}{2}\frac{R_c\gamma}{\Delta\rho g}\right)^{1/3}$$



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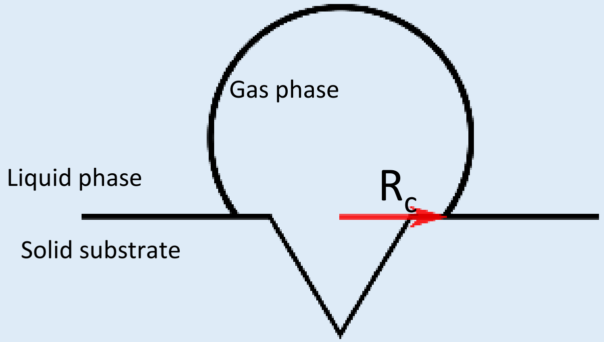

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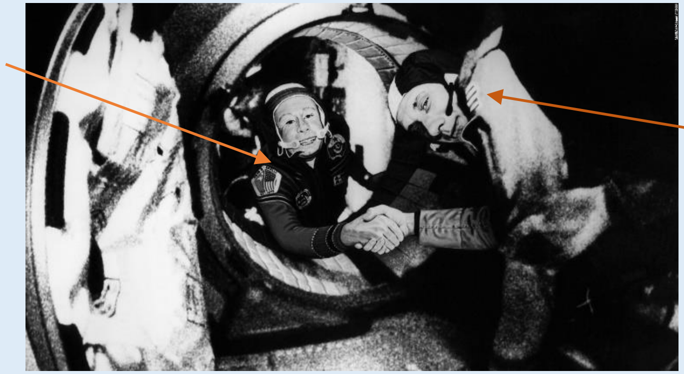
Because of this, if you remove gravity, you end up with some kind of foam with huge bubbles.

Leonov (Sovietic)



Stafford (American)

These guys didn't drink Champagne on July 17th 1975.

Flying to the sky

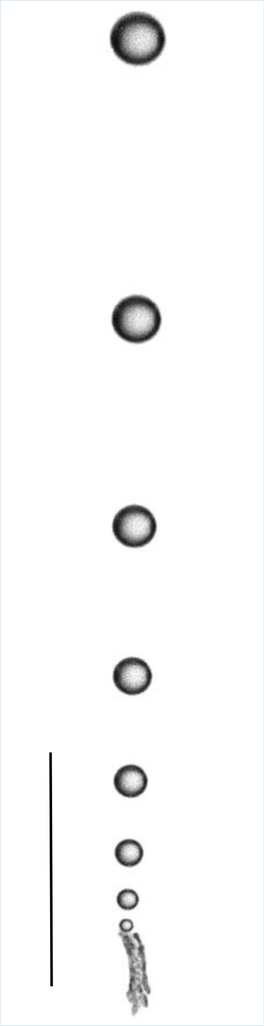
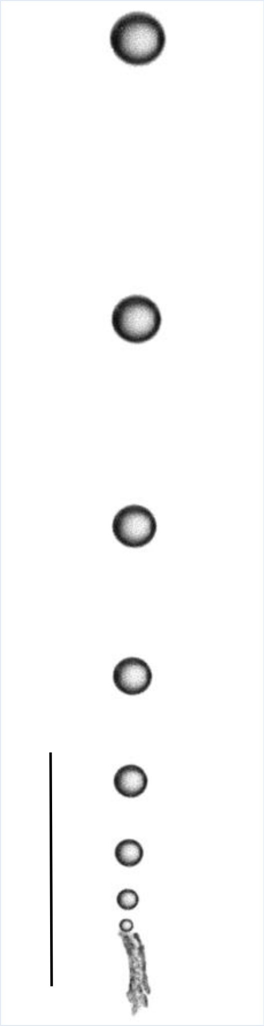


Photo by Liger-Belair
Bar=1mm

The bubble keeps growing while rising through the liquid.
The buyancy force increases, the bubble accelerates.

=> An elongated glass features bigger bubbles than a « flatter » one.

Flying to the sky



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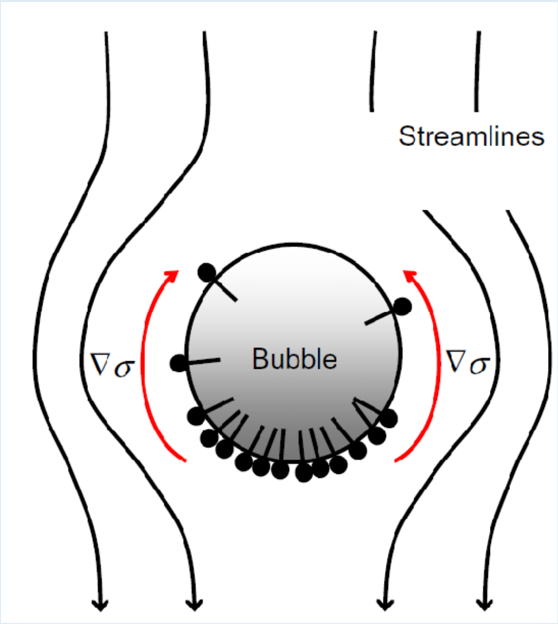
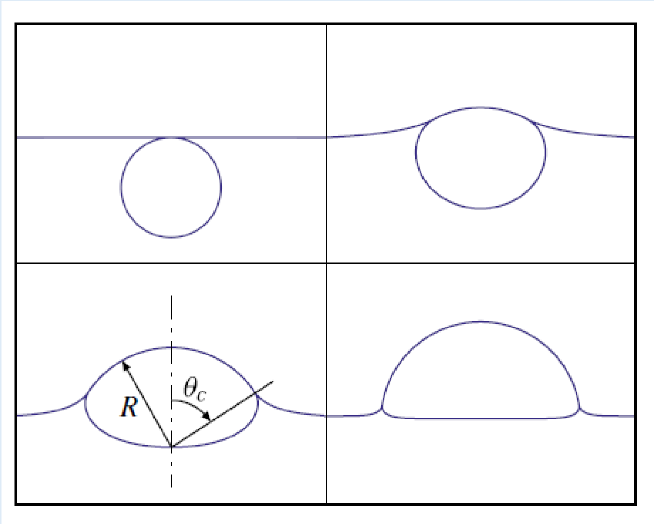


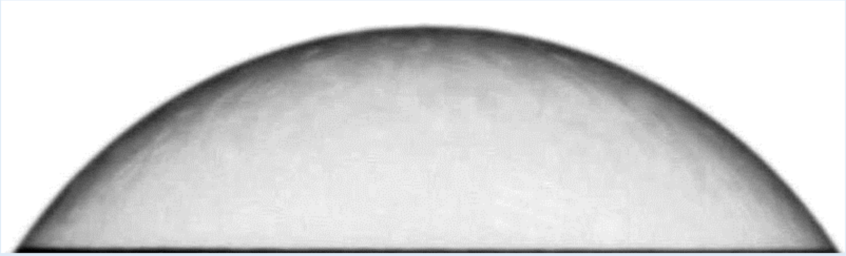
Surface active compounds may slow down the ascent of the bubble

On the edge

- The bubble reaches the upper boundary of its native liquid environment.
- Some part of it emerges while another remains under the surface level.
- It takes an equilibrium macroscopic shape, in the form of a spherical cap and its lifetime is counted from now on because of the film thinning and subsequent inevitable rupture.

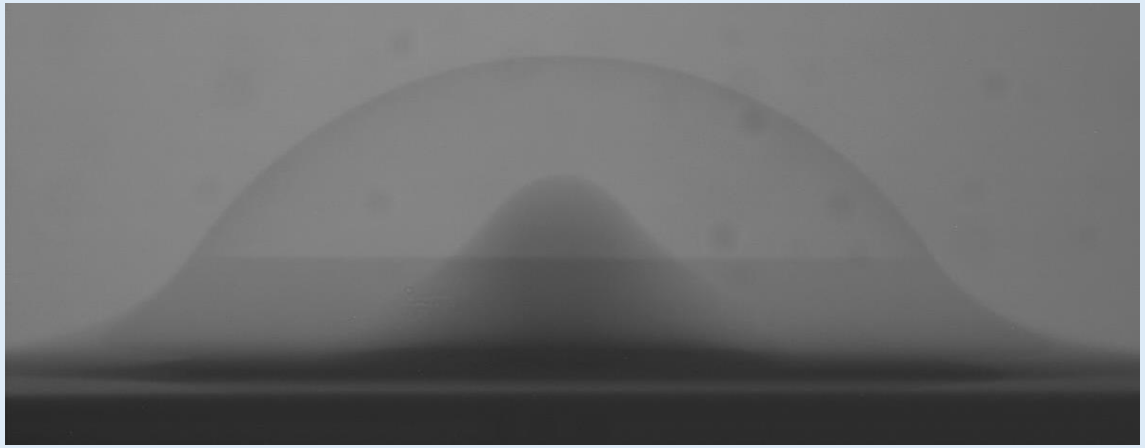


Bubble shape dependance on its size



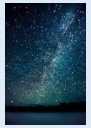
Just for the beauty of it…
A bubble at the surface of a liquid container

Bursting through the sky



Bursting bubble and subsequent « Worthington Jet ». Frame rate 3.75 s^{-1}

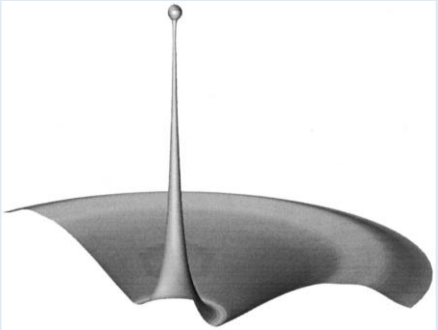
Fast pressure drop inside the bubble.
Hydrostatic and curvature-induced pressure not balanced => Worthington Jet



Bursting through the sky

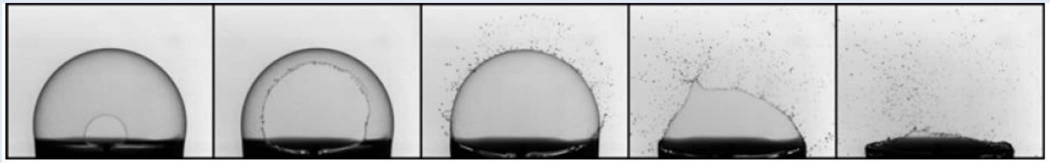
Aerosols production : 2 mechanisms

Destabilisation of the Worthington Jet



Up to several droplets
Tipically 100 μm

Thin film atomization



Up to few hundreeds of droplets
Tipically 100 μm

Outcome

- Bubbles promote the exchanges of mass (and heat) from the bulk to the atmosphere

➔Impact on fizzy drinks consumer's sensations

➔Also matters for the climate modelling (aerosols allow for cloud production)

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- Don't forget to drink alcohol with moderation

Thank you for
you attention !