Colloids & Interface Project

Why is Surface Tension a Force Parallel to the Interface?

Presented By - Group 8

Introduction

What is Surface Tension?

- It's the tendency of liquid surfaces to shrink into the minimum possible surface area.
- We see it everywhere: water droplets, insects walking on water, paperclips floating .

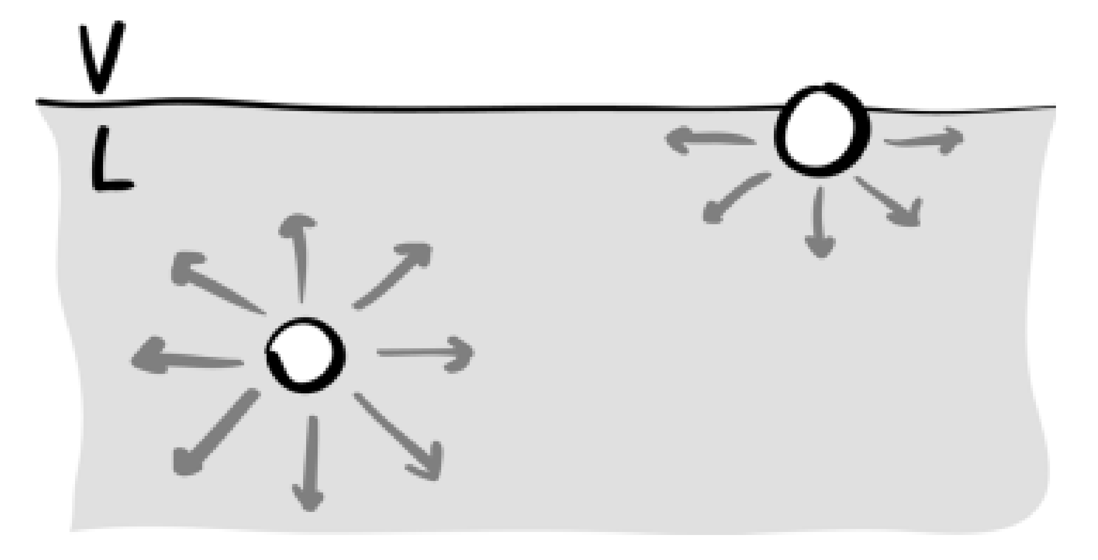
Two Common Definitions:

<u>Thermodynamic View:</u> An energy per unit area ($\gamma=\partial G/\partial A$). The energy required to create a new surface .

<u>Mechanical View:</u> A force per unit length ($\gamma=F/L$). A force acting tangentially (parallel) to the surface .

Problem

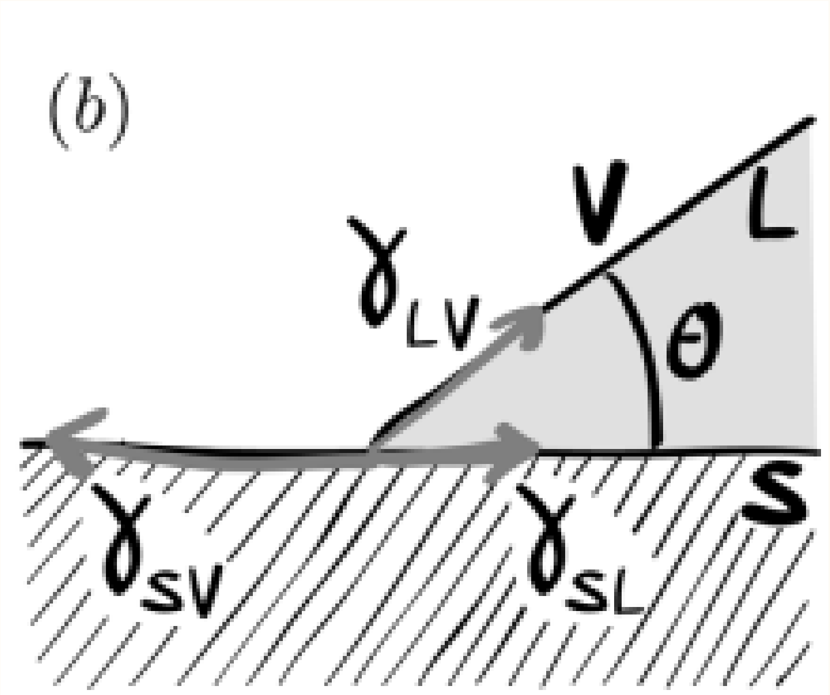
- A simple diagram of molecules shows that surface molecules have "missing bonds" .
- This implies a net downward (perpendicular) force .
- **<u>Our Project Question:</u>** How can the force be parallel if the molecular attraction seems to be perpendicular?



Our Project's Key Questions

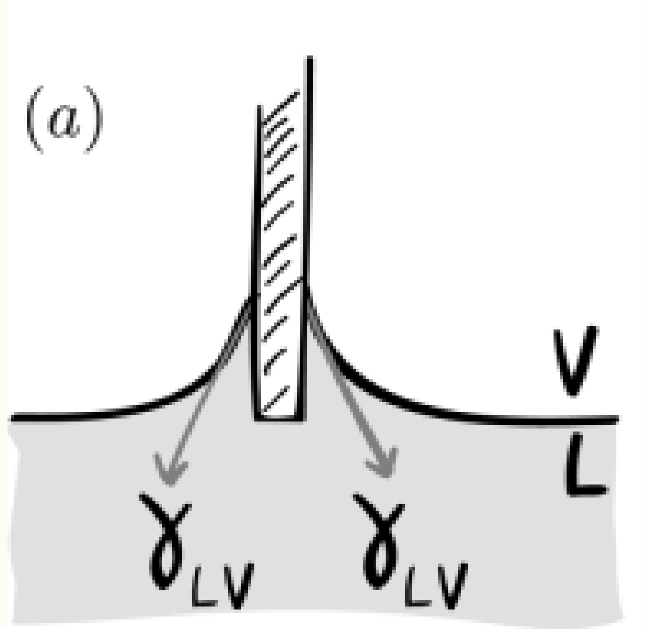
- Based on our research paper, we will answer three key questions that many students face

01 Why is surface tension a parallel force, even though the simple "missing bonds" diagram suggests a perpendicular one?



02 Why does the classic "force balance" diagram for Young's Law (at a contact line) seem to have an unbalanced vertical force?

03 Why do we draw three forces for a droplet on a surface but only one when pulling a plate from a liquid?



Theory

Why the "Missing Bonds" Diagram is Incomplete:

- It only shows attractive forces (like van der Waals) .
- A stable liquid is a balance of two types of forces :

1. Long-Range Attraction (e.g., van der Waals) .
2. Short-Range Repulsion (from electron clouds, "excluded volume") .

- In the bulk, these forces are balanced in all directions (isotropic).
- The "problem" is resolved by analyzing the balance at the interface.

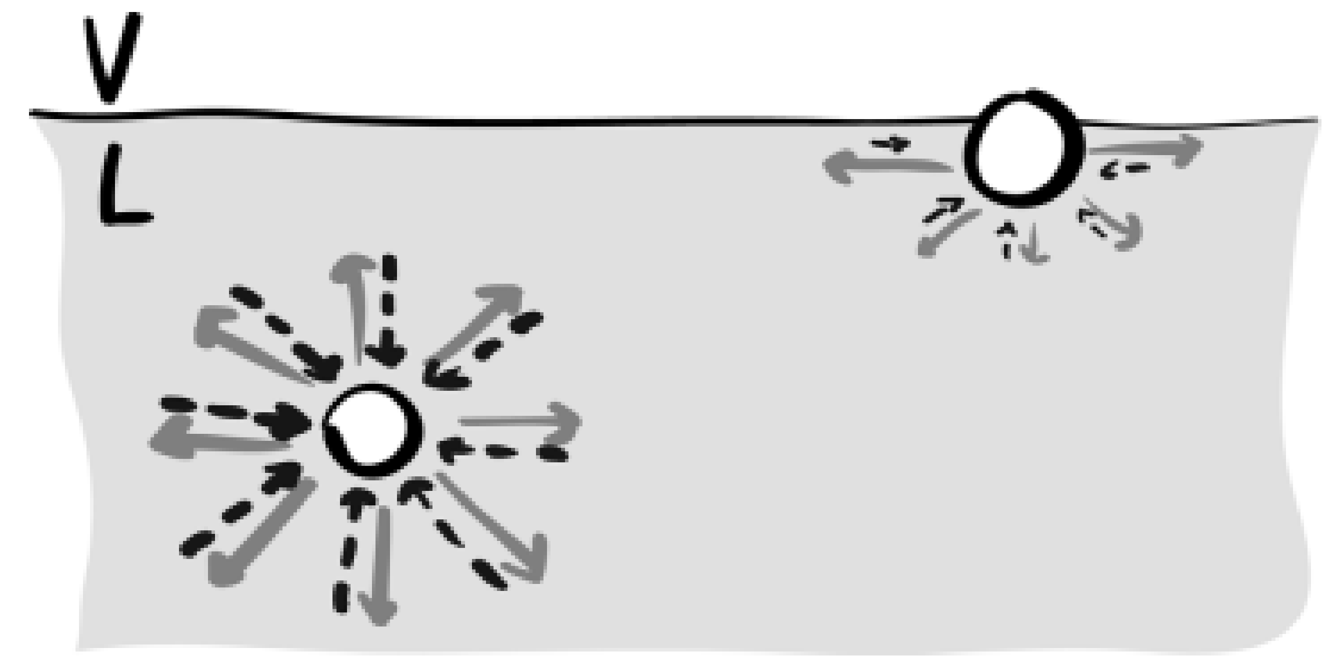


Fig. 6. Sketch showing repulsive (dashed black arrows) and attractive (gray arrows) forces in the bulk and at the surface.

Thermodynamics

- From a thermodynamic view, surface tension (γ) is simply the excess free energy per unit area.
- It’s the energy cost to create one new square meter of surface.
- This is why its units are J/m2 (energy per area).
- This "energy" view is 100% correct for calculations, but it doesn't explain where the mechanical force comes from.

"Perpendicular" Force

- We are looking at the forces normal (perpendicular) to the surface. The net force must be zero for the surface to be stable.

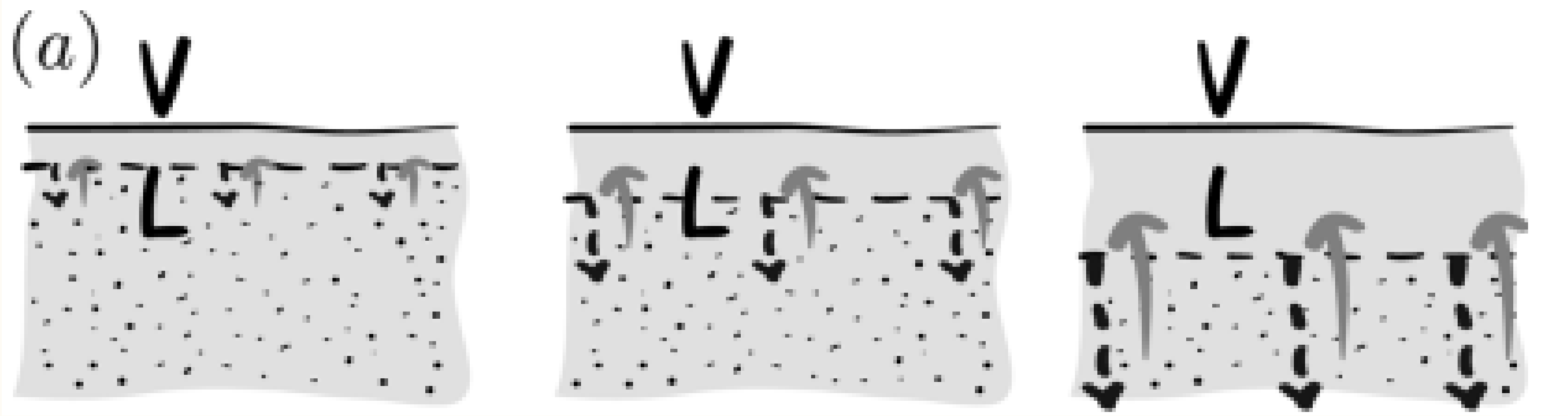
- An inward "pull" from long-range Attraction (solid arrows).
- An outward "push" from short-range Repulsion (dashed arrows) from the dense liquid below.

$$F_{net,\perp} = F_{attraction,\perp} + F_{repulsion,\perp}$$

$$F_{attraction,\perp} \text{ (down)} = -F_{repulsion,\perp} \text{ (up)}$$

Therefore, the total net force in the perpendicular direction is zero.

$$F_{net,\perp} = 0$$



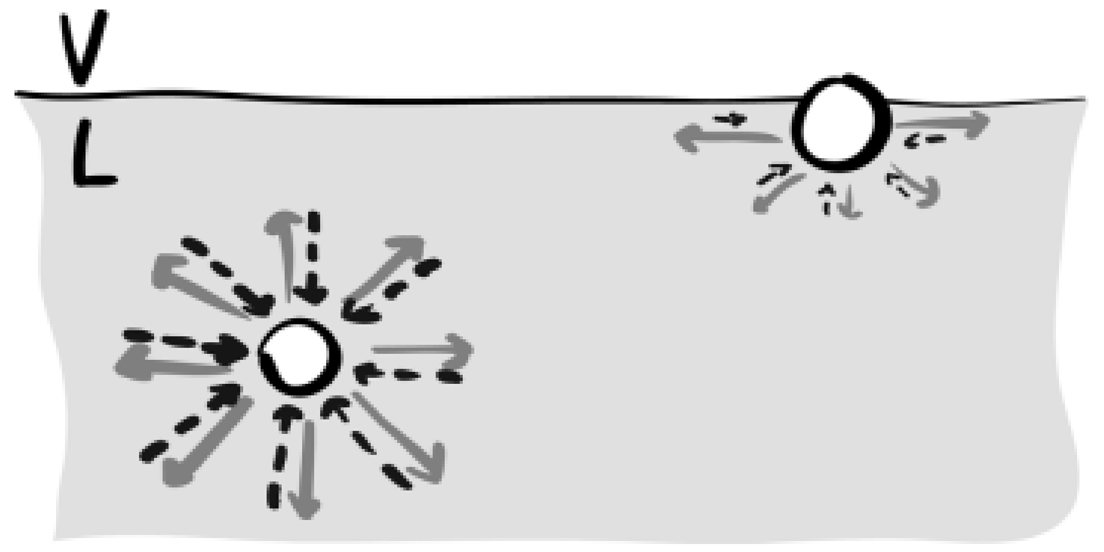


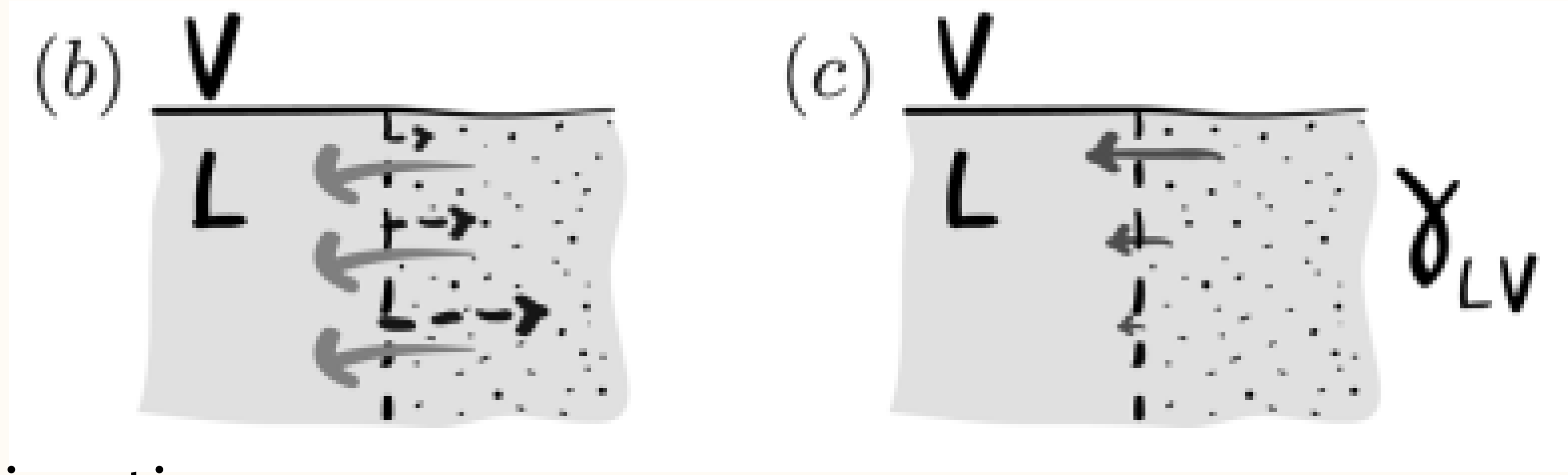
Fig. 6. Sketch showing repulsive (dashed black arrows) and attractive (gray arrows) forces in the bulk and at the surface.

- **Conclusion:** The net perpendicular force is zero. The "missing bonds" pull is real, but it is perfectly canceled by repulsion from the liquid below.

"Parallel" Force

Now, we are looking at the forces parallel (tangential) to the surface. Here, the forces are unbalanced.

- Repulsion (short-range) is isotropic. The molecule is "pushed" equally by all its neighbors on the surface.
- Attraction (long-range) is anisotropic. The molecule is "pulled" by its neighbors on the surface, but it's not pulled by the empty vapor side.



- $F_{||} = F_{attraction,||} + F_{repulsion,||}$
- Because attraction is stronger than repulsion in this direction:

$$F_{attraction,||} > F_{repulsion,||}$$

Stress Anisotropy, $\Pi(z) = P_{normal}(z) - P_{tengential}(z)$

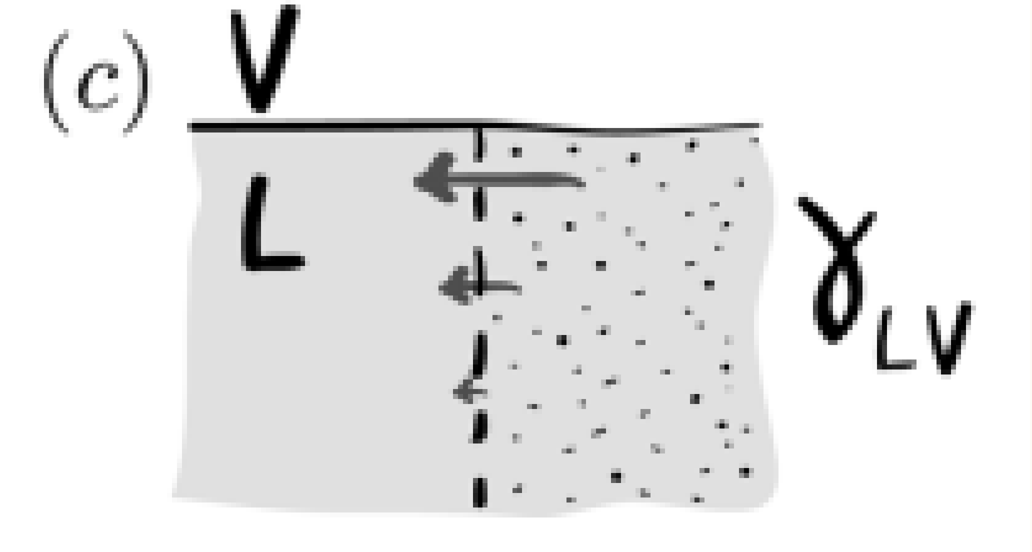
Surface Tension (γ_{LV}) is the total (integral) of this net force across the entire interface thickness.

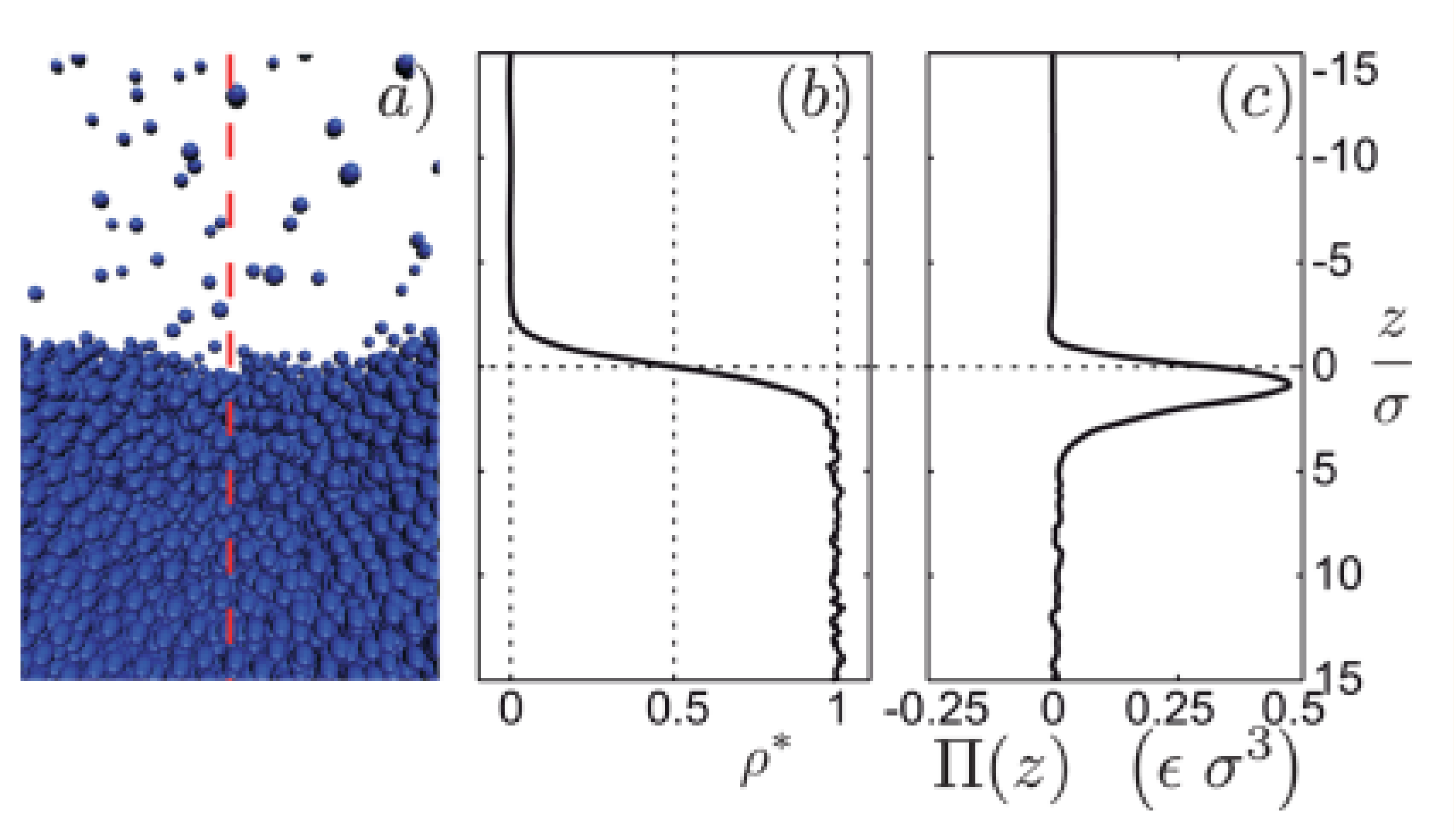
$$\gamma_{LV} = \int \Pi(z)dz$$

In the parallel direction, the attraction is stronger than the repulsion. This net tangential attractive force is what we call surface tension.

"Stress Anisotropy"

- This force exists in a very thin layer right at the interface.
- If you imagine cutting the liquid in two (the dotted vs. plain region), the two halves pull on each other.
- Deep in the bulk, the "push" (repulsion) and "pull" (attraction) are equal.
- But at the surface, the "pull" is stronger than the "push" .
- This imbalance, or "stress anisotropy," is the mechanical force γLV.





This is a "snapshot" of the molecules. You can clearly see the dense liquid at the bottom and the low-density gas at the top.

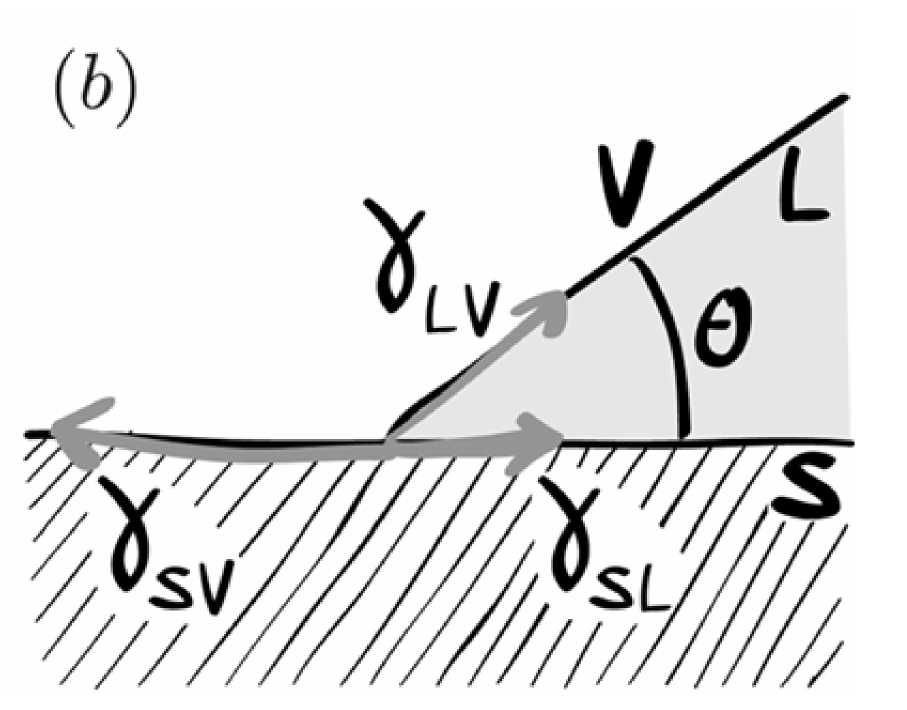
- This graph plots the net parallel force (Π(z)) versus the vertical position (z).
- At the interface: A positive "bump" appears. This shows there is a strong, net parallel force that exists only in that thin interface region.
- This "bump" is the surface tension. The area under this curve is the total surface tension, γLV.

The Contact Line (Young's Law)

- **This brings us to Question 2: What happens when a solid, liquid, and vapor meet?**

- This is often governed by Young's Law

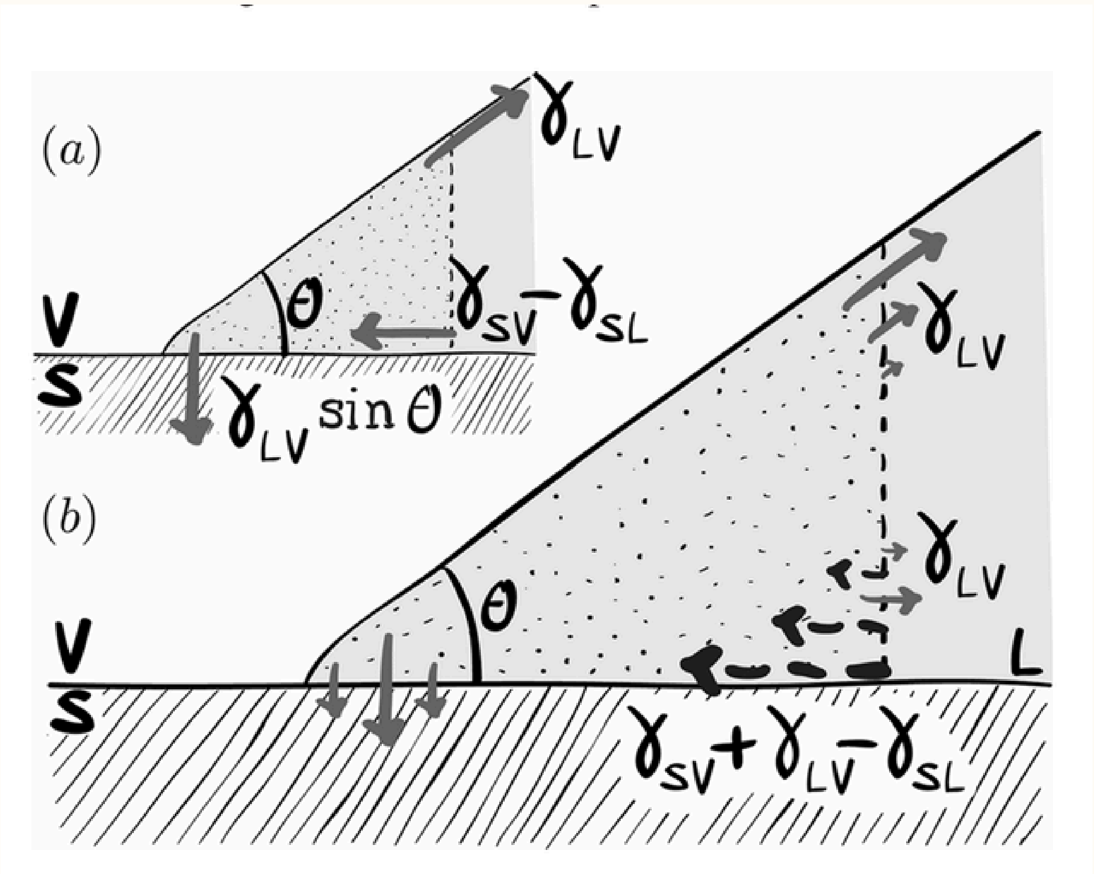
  $\gamma_{LV}\cos\theta=\gamma_{SV}-\gamma_{SL}$
- We often consider this as a "force balance"

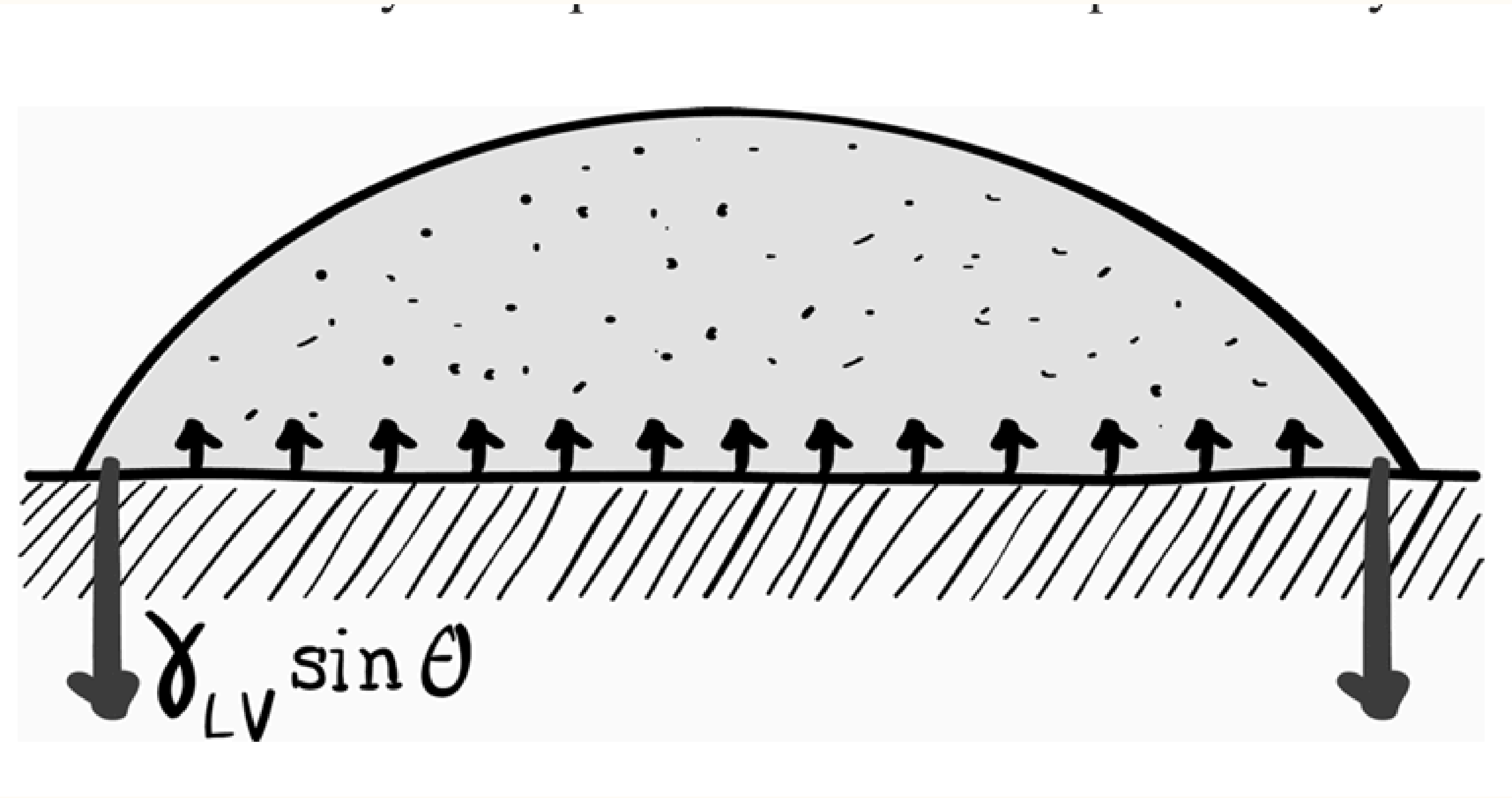


- **The Problem (Q2):** This diagram is not in equilibrium! It has an unbalanced upward force of $\gamma_{LV}\sin\theta$.
- The classical diagram produces a vertical component: $\gamma_{LV}\sin\theta$ (upwards) which does not have an opposing force shown.
- This suggests an apparent imbalance → the liquid wedge should lift upward.

The Missing Vertical force

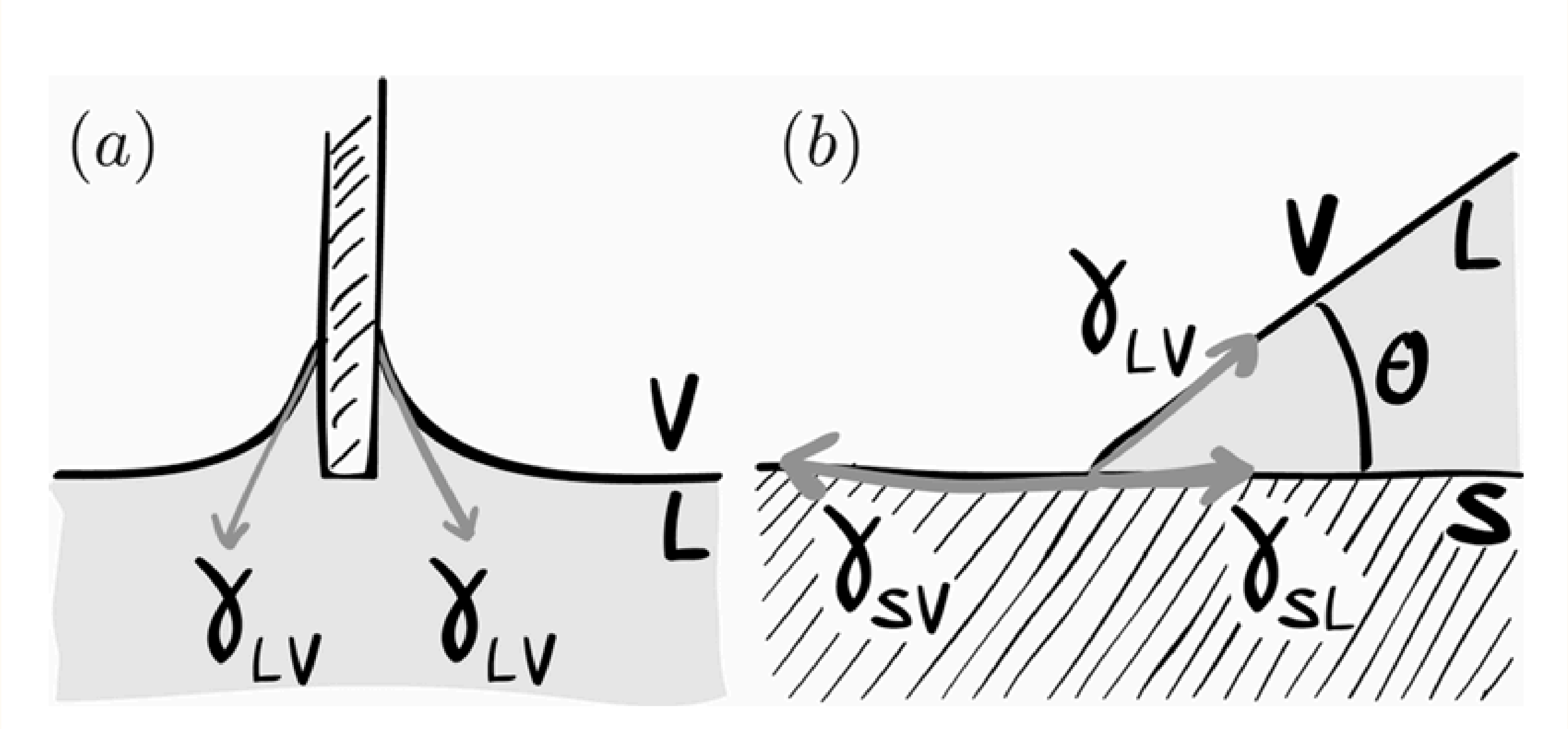
- The classical Young's diagram misses a downward force exerted by the solid on the liquid near the contact line.
- This solid-on-liquid attraction is normally balanced by repulsion, but repulsion weakens sharply near the contact line.
- As a result, a localized downward force appears, equal in magnitude to γLV sinθ.
- This downward force exactly cancels the upward vertical component of the liquid–vapor surface tension.
- Therefore, the liquid wedge is in perfect mechanical equilibrium, and no upward lifting occurs.





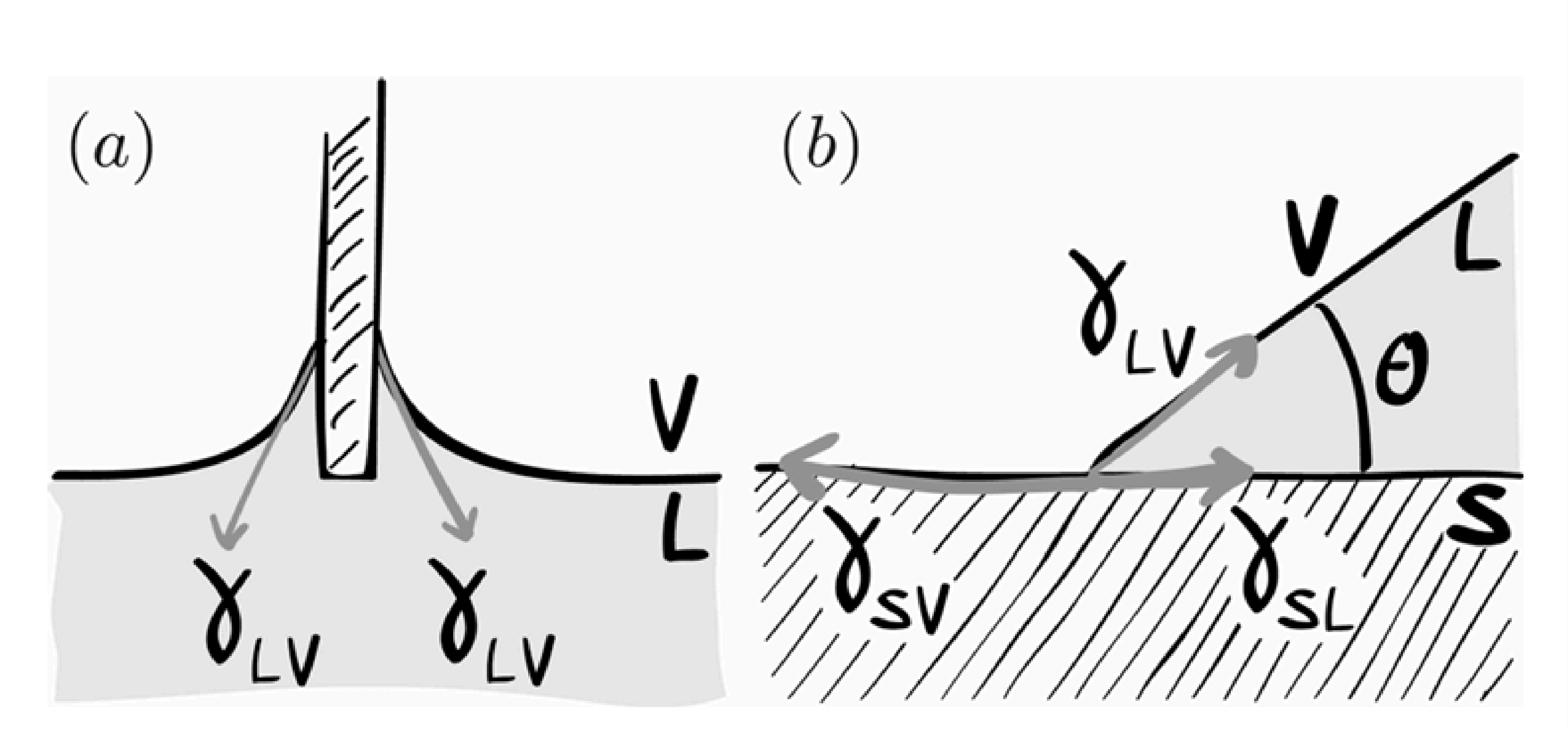
Why Diagrams Show Different Forces

- Why does Young’s diagram show three forces (γLV, γSL, γSV)?
- Why does the plate-pulling diagram show only one force (γLV cosθ)?
- Are γSL and γSV actual forces acting on the solid?
- Why do the two diagrams seem inconsistent with each other?
- How do we avoid contradictions in capillarity force diagrams?



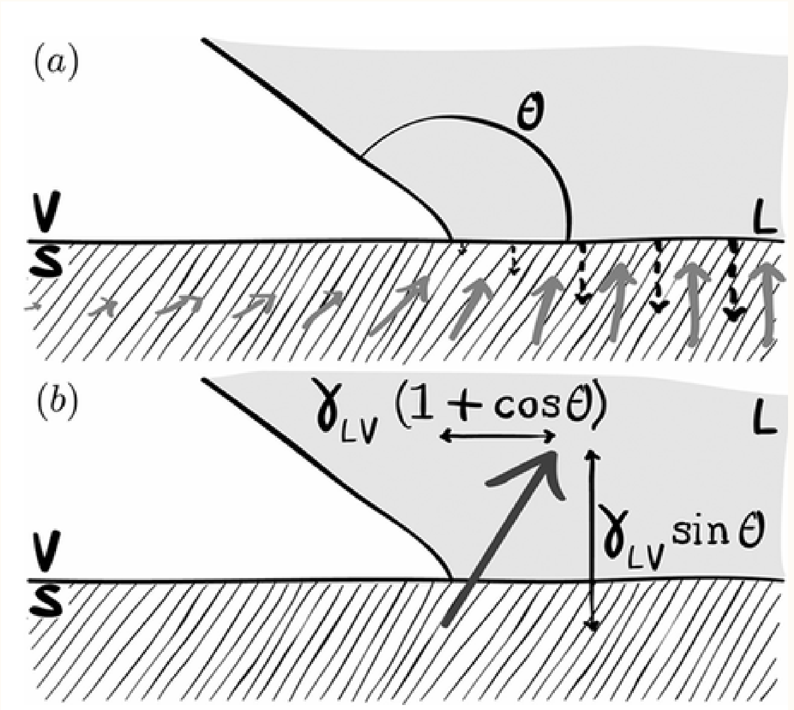
Why Diagrams Show Different Forces

- The forces drawn depend entirely on which system is chosen (liquid or solid).
- Young's diagram uses the liquid wedge as the system → all three tensions appear.
- Plate experiment uses the solid plate as the system → only $\gamma_{LV} \cos\theta$ acts on it.
- γ_{SL} and γ_{SV} are surface energies, not mechanical pulls on the solid.
- Using the correct system removes all contradictions in the diagrams.



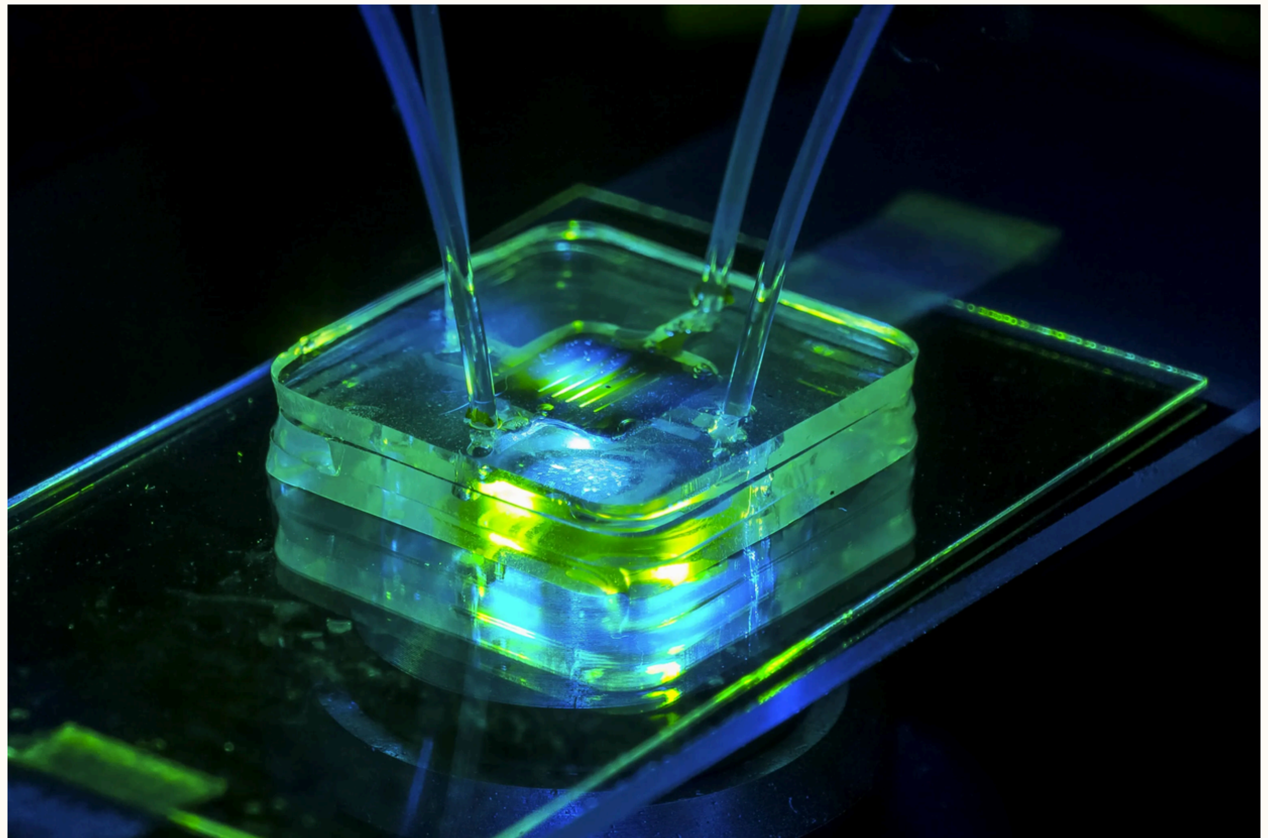
Applications & Importance

- **Accurate Wetting Predictions:**
  Correct force interpretation improves understanding of Young's Law, wetting, and contact angles.
- **Soft Materials & Wetting Ridge:**
  The "missing" vertical force creates measurable surface deformation in soft solids (e.g., gels, elastomers, cell membranes and tissues).
- **Design of Superhydrophobic Surfaces:**
  Fundamental for Wenzel & Cassie-Baxter models used in self-cleaning and anti- wetting technologies.
- **Nanotechnology & Droplet Manipulation:**
  Essential in microfluidics, nanodroplet control, inkjet printing, and lab-on-chip devices.
- **Bridges Theory & Simulation:**
  Links thermodynamics, molecular dynamics, and real mechanical forces → resolves long-standing paradoxes.



Conclusion

- Surface tension acts parallel to the interface because of anisotropic molecular attraction, not “missing bonds.”
- Normal (perpendicular) forces cancel microscopically, leaving a net tangential force responsible for γ.
- Classical Young’s force diagram is incomplete — it misses the downward solid-on-liquid force $\gamma LV \sin\theta$.
- Using the correct system (solid vs. liquid) resolves why diagrams show different forces.
- This unified view connects thermodynamics, molecular physics, and real mechanical behavior, strengthening our understanding of wetting.



Thank you