Fluid Bridge

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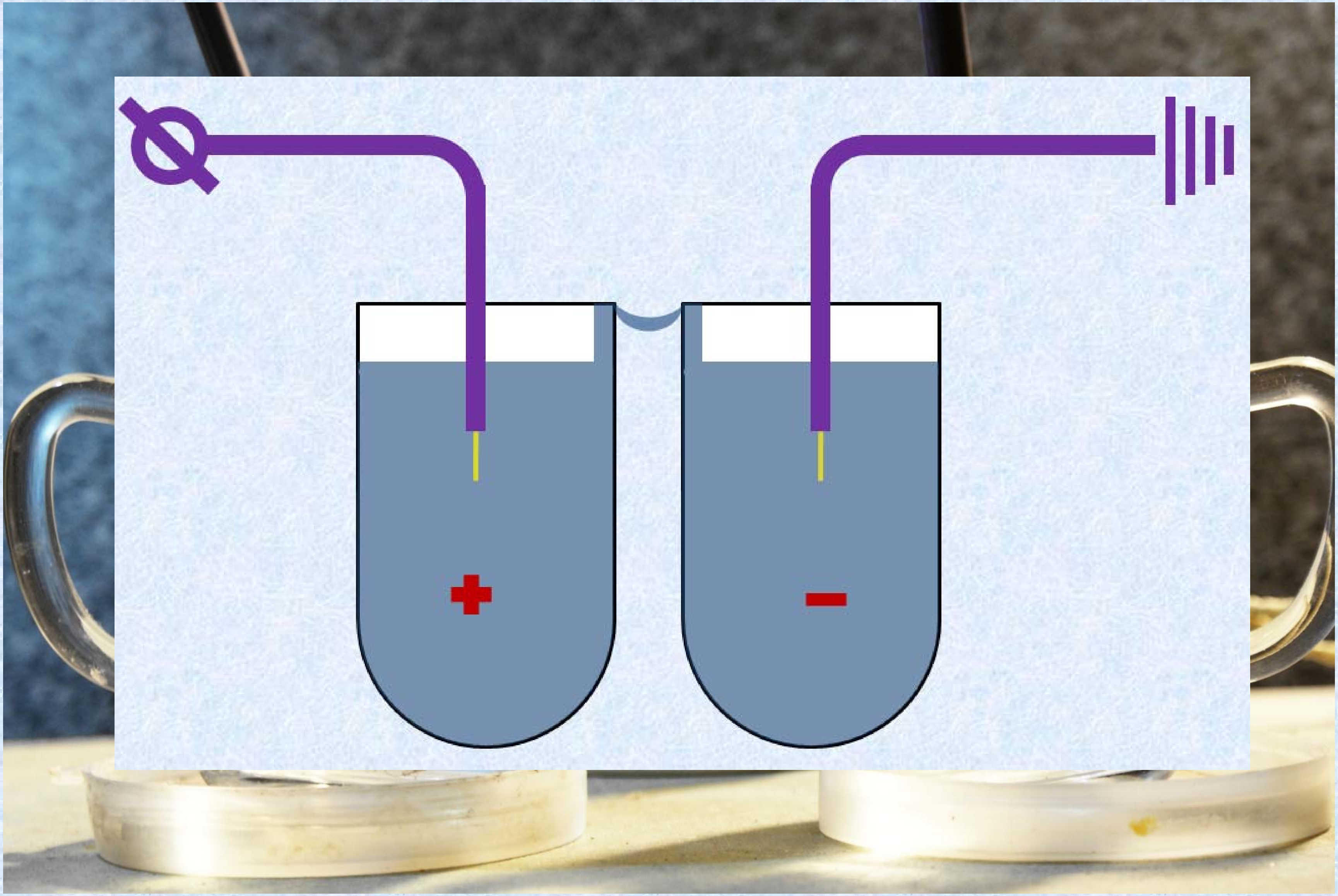
If a high voltage is applied to a fluid (e.g. deionized water) in two beakers, which are in contact, a fluid bridge may be formed. Investigate the phenomenon. (High voltages must only be used under appropriate supervision - check local rules.)

Presentation Plan

1. Experiment
2. Reasons of fluid bridge formation
3. Parameters of our bridge
4. Comparison of theory and experiments
5. Other effects
6. Conclusion

Experiment



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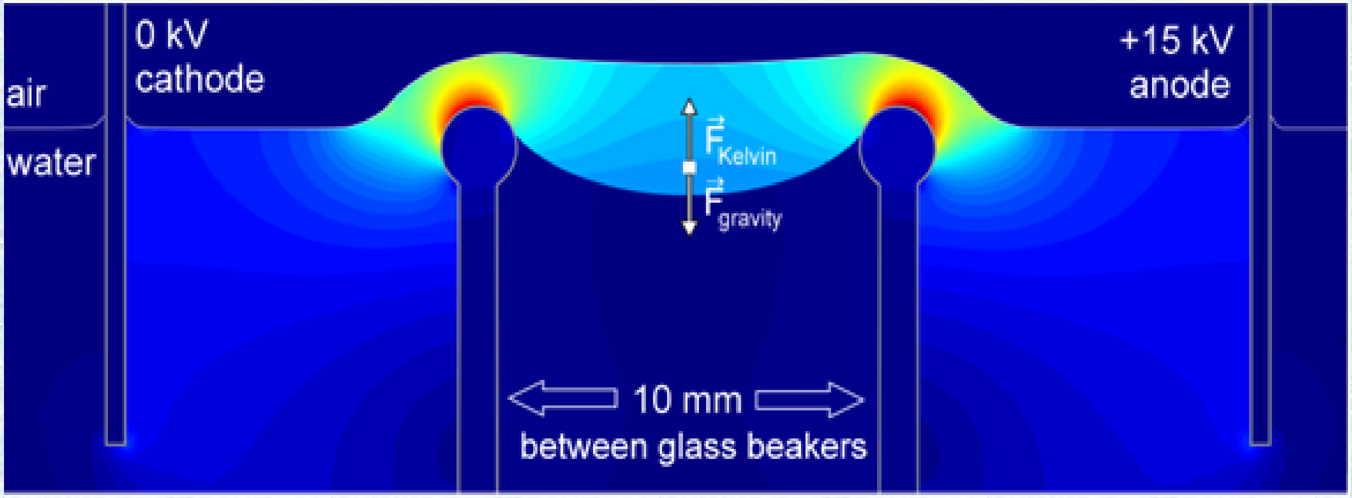
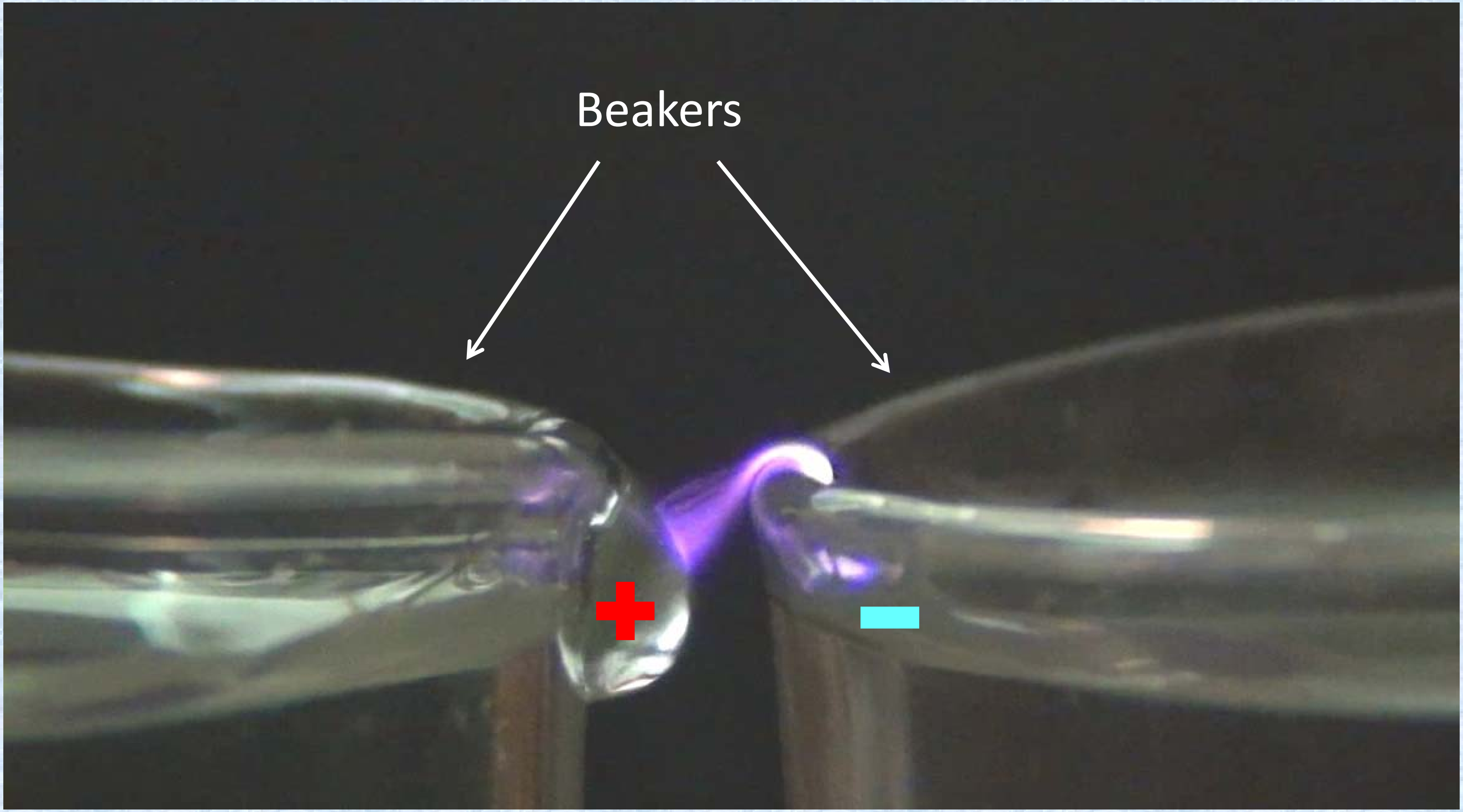
Factors of fluid bridge formation



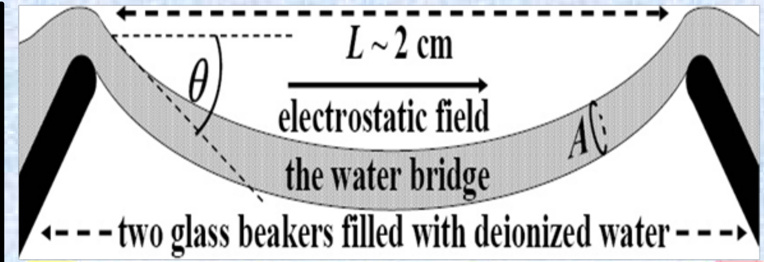
- ✓ Electric forces
- ✓ Surface tension
- ✓ Structurization of water molecules due to electric field

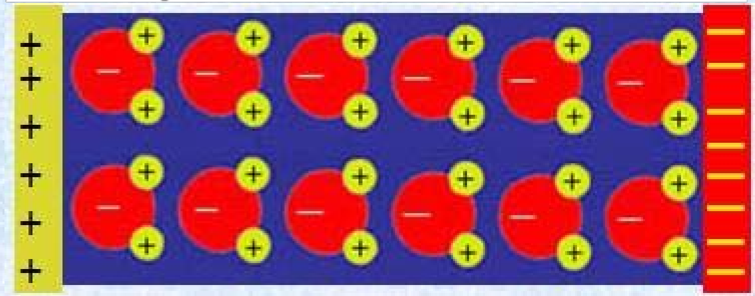
Process Beginning



Force acting on a fluid cylinder

L	-	Distance between beakers
L_c	-	Bridge length
$A=\pi R^2$	-	Cross-section area.
E	-	Electric field intensity along the cylinder axis
$D=\varepsilon E$	-	Electric induction (displacement)
ε	-	Dielectric permeability





- ✓ Due to polarization, at the end of the cylinder appears charge equal to: $\pm Q$.
- ✓ In Gauss unit system:

$$4\pi\sigma = \Delta D = (\varepsilon - 1)E = 4\pi \frac{Q}{A} \quad (1)$$

- ✓ Cylinder tension force:

$$\tau = QE$$

- ✓ From (1) -

$$\frac{\tau}{A} = \left(\frac{\varepsilon - 1}{4\pi}\right) E^2 \quad (2)$$

Length of the liquid cylinder

L -	Distance between beakers
L_c -	Bridge length
$A=\pi R^2$ -	Cross-section area.
E -	Electric field along the cylinder axis
$D=\varepsilon E$ -	Electric induction (displacement)
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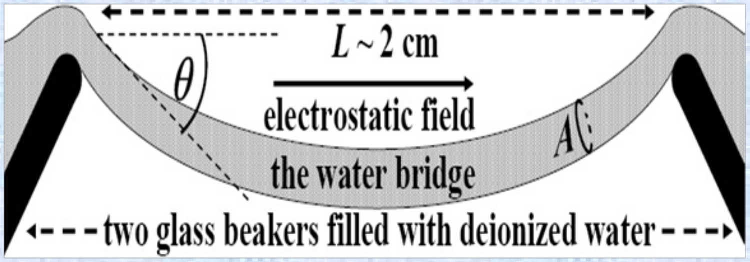
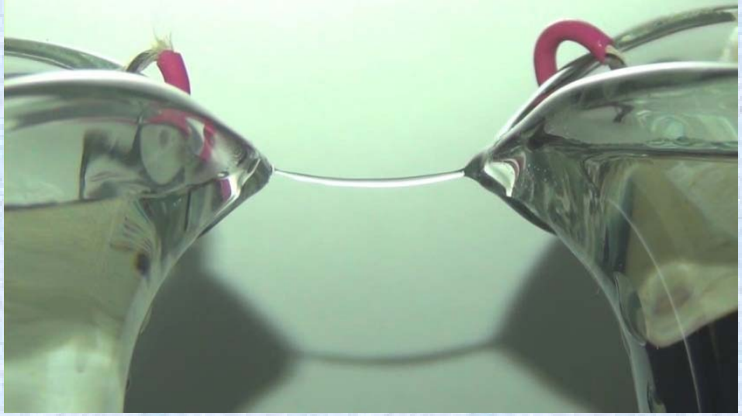




- ✓ $\rho = 1g/cm^3$
- ✓ $g=980cm/sec^2$
- ✓ $E=10KV/cm \approx 35\ CGSE$
- ✓ $\varepsilon=80$

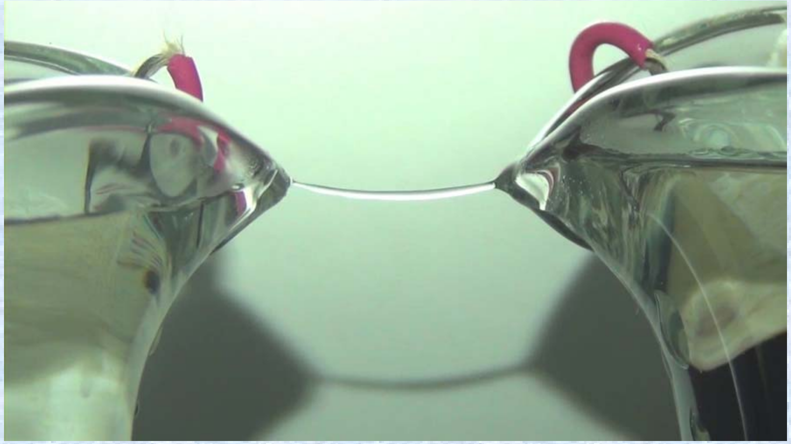
Weight of the bridge is $Mg=\rho g A L_c$. It is compensated by tension force $Mg = 2\tau\ \sin\theta$

Taking in account (2) and assuming that $L_c \approx \dfrac{L}{\cos\theta}$, we get

$$L \approx \frac{(\varepsilon - 1)E^2}{4\pi\rho g} \cdot \sin 2\theta$$

If $\theta\approx15^\circ$, We get approximately $L \approx 2\ cm$

Shape of fluid bridge



- Water bridge is "elastic liquid heavy rope" fixed by its ends.
- Bridge has so called "Chain" shape.
- Bridge "linear specific" weight is – $\rho g A$.
- Tension force – τ .
- Distance between fixing points – L .

Heavy chain line equation is (*D.Douglas*, *R.Thrash*) :

$$y(x) = \frac{\tau}{\rho g A} \cdot \left[cosh\left(\frac{\rho g A}{\tau} x\right) - 1 \right] \approx \frac{\rho g A}{\tau} x^2 \qquad (3)$$

$$\frac{\tau}{A} = \left(\frac{\varepsilon - 1}{4\pi}\right) E^2 \qquad (2)$$

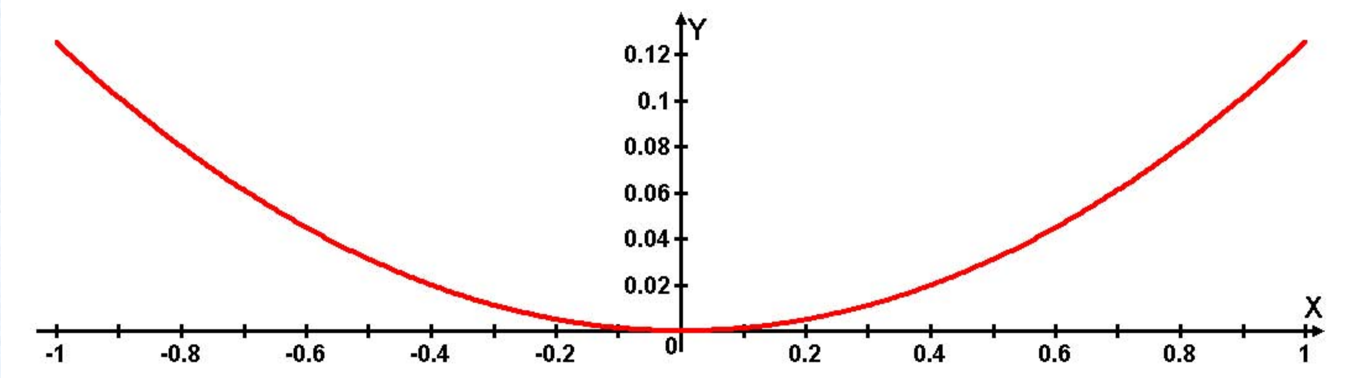
Inserting (2) into (3) we get:

$$y(x) = \frac{(\varepsilon - 1)E^2}{4\pi\rho g} \cdot \left[cosh\left(\frac{4\pi\rho g}{(\varepsilon - 1)E^2} x\right) - 1 \right] \approx \frac{4\pi\rho g}{(\varepsilon - 1)E^2} x^2 \qquad (4)$$

Maximal sag:

$$h = \frac{(\varepsilon - 1)E^2}{4\pi\rho g} \cdot \left[cosh\left(\frac{2\pi\rho g L}{(\varepsilon - 1)E^2}\right) - 1 \right] \approx \frac{\pi\rho g L^2}{2(\varepsilon - 1)E^2} \qquad (5)$$

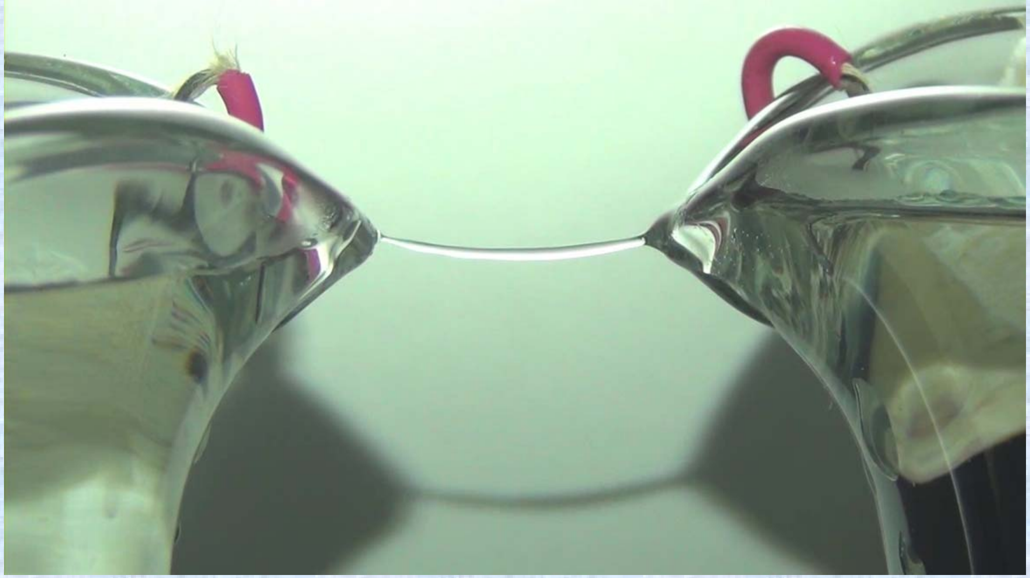
Comparison to experiment



We can estimate the "sag" of the bridge in our experiment:

- ✓ $L = 2cm$
- ✓ $\rho = 1g/cm^3$
- ✓ $g=980cm/sec^2$
- ✓ $E=10KV/cm \approx 35$ CGSE
- ✓ $\varepsilon=80$

In our case $h \approx 1$ mm



Surface tension

Surface tension also compensates gravitational force:

$$\rho g A L_c \cong 2 l \gamma \theta$$

Surface tension also tries to split the bridge into droplets

In case of electric field, it is energetically “favorable” for bridge surface to stay unperturbed (*Aerov 2011*).

For bridge stability, electric field has to be larger than critical one (*Aerov 2011*) :

$$E \geq E_{critical} \sim \frac{L\sqrt{\gamma}}{\varepsilon\sqrt{A}}$$

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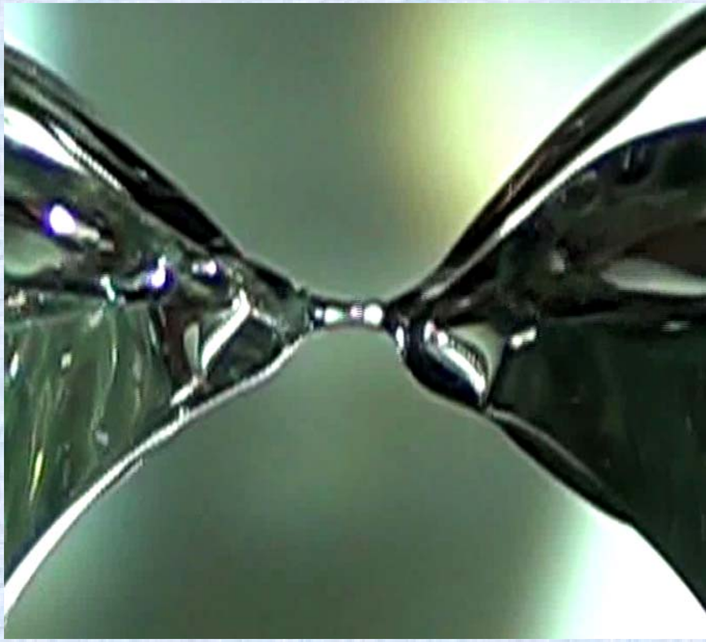
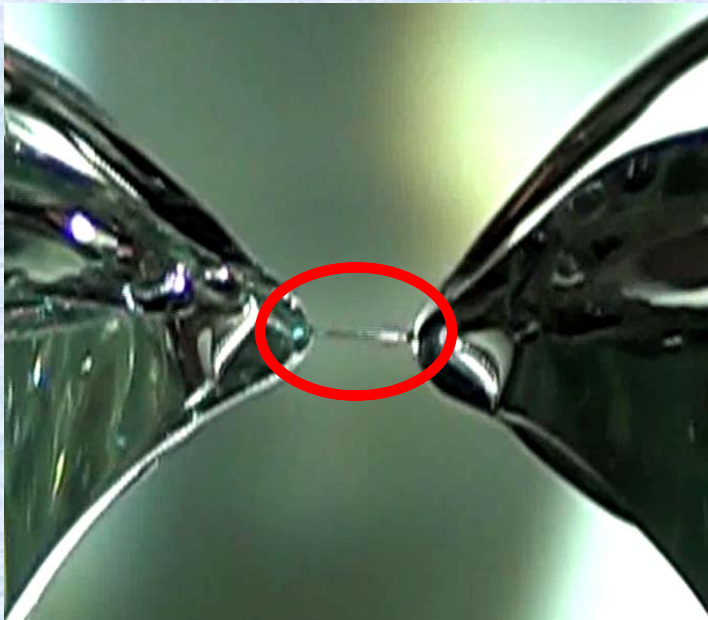
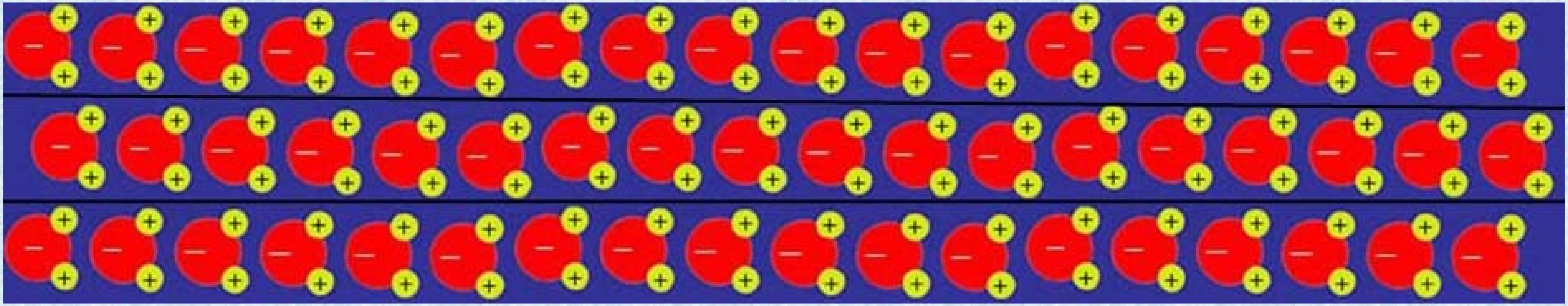
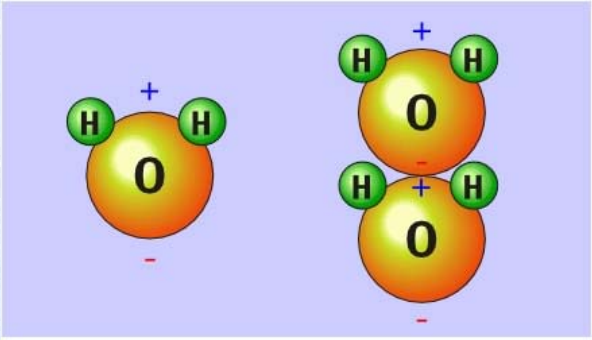


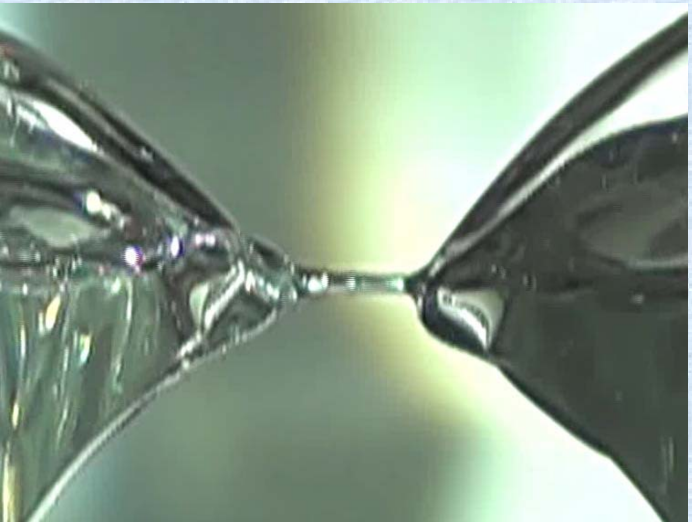


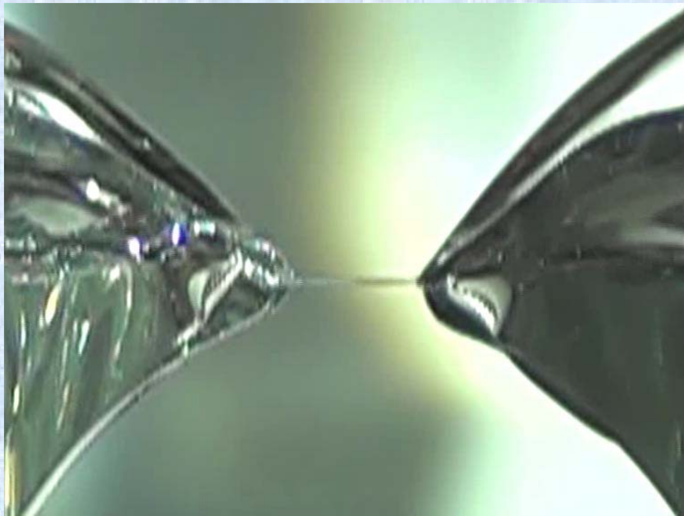
Structure of the bridge





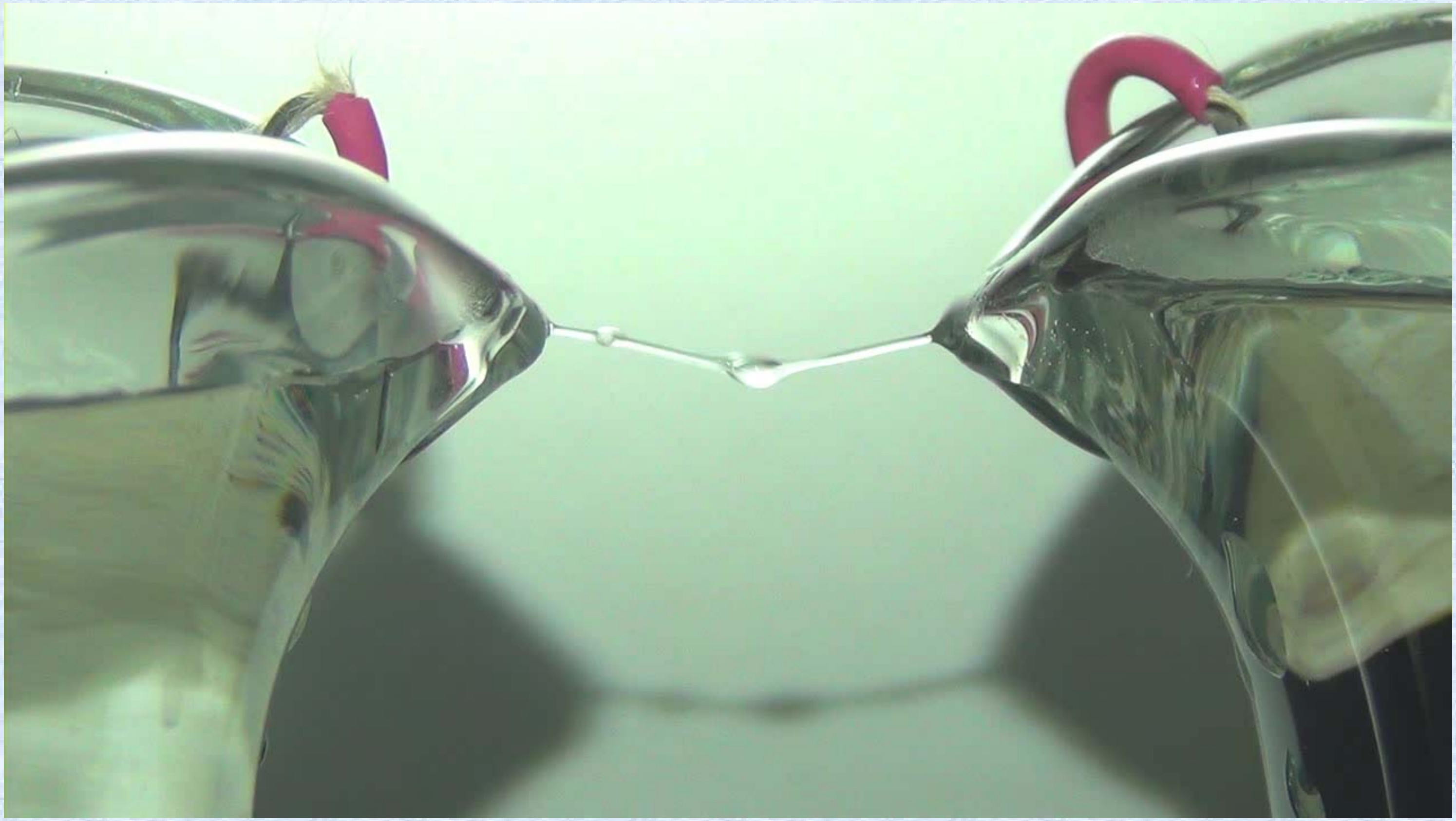
Bridge structure



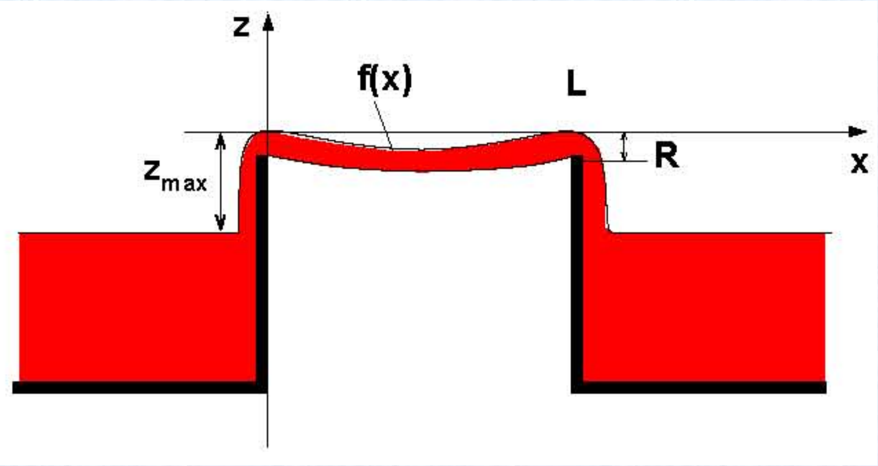


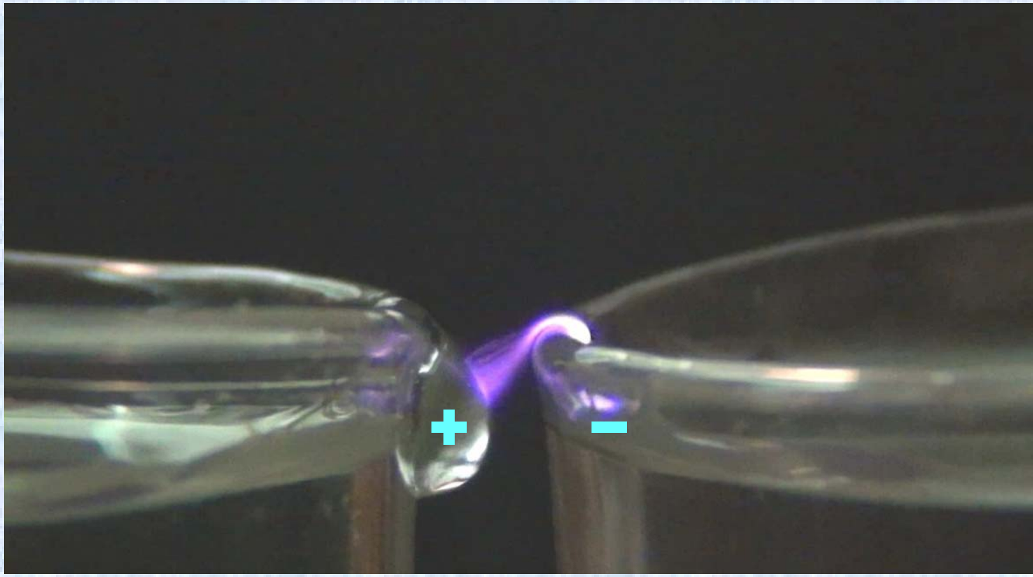
Various effects

- Crawling on the wall
- Evaporation
- Liquid flow in beakers
- Droplets



Crawling on the wall





In case of electric field, Bernoulli equation is as follows :

$$P + \frac{1}{2}\rho v^2 + \rho g z - \frac{(\varepsilon - 1)E^2}{8\pi} = const$$ *(Widom et al 2009)*

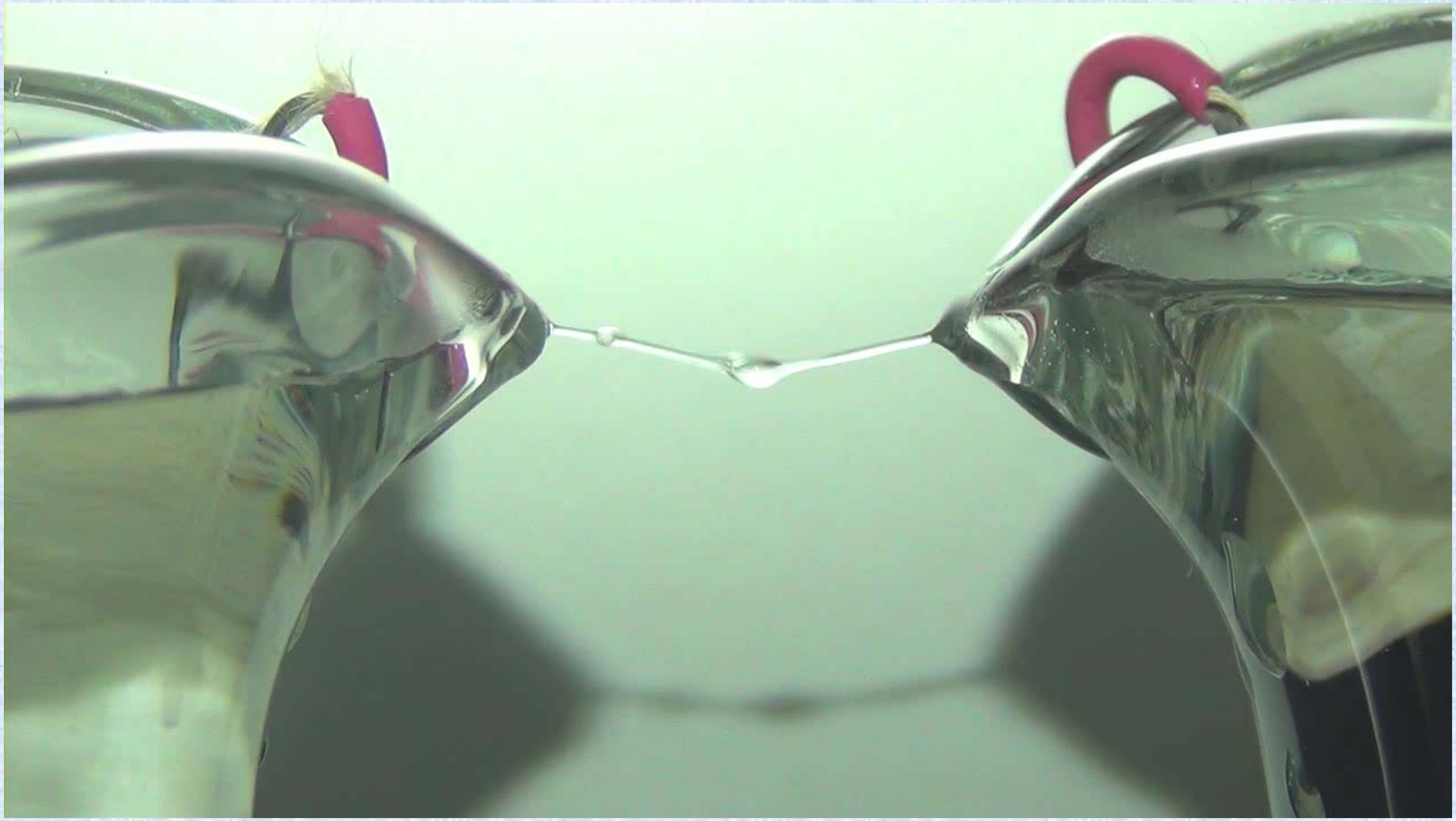
Polarized dielectric fluid can crawl on the wall on a height equal to:

$$z = \frac{(\varepsilon-1)E^2}{8\pi\rho g}$$

In our case, water can crawl on wall up to **2–3 cm** height

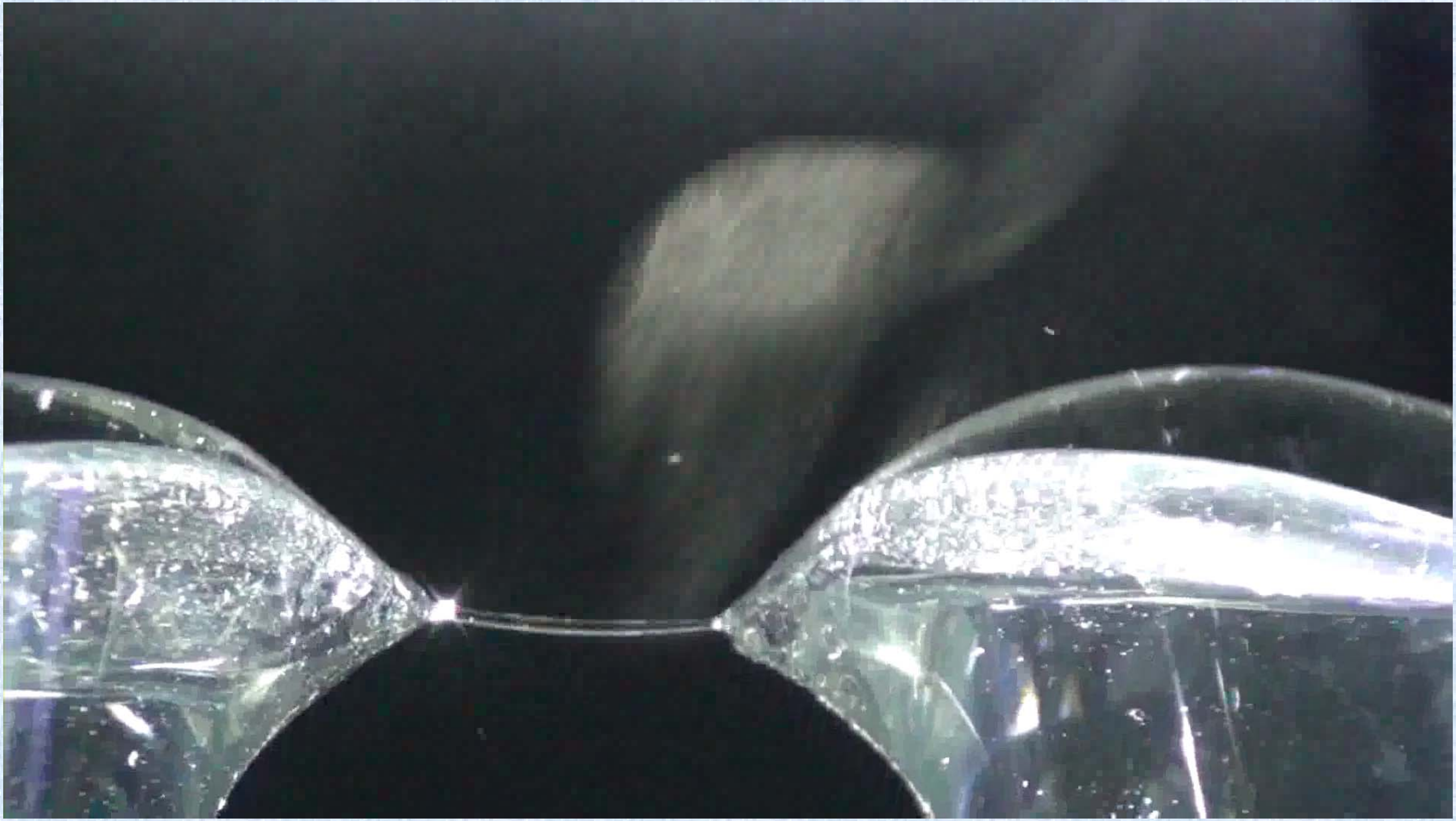
“Droplet effect”

- Droplet effect



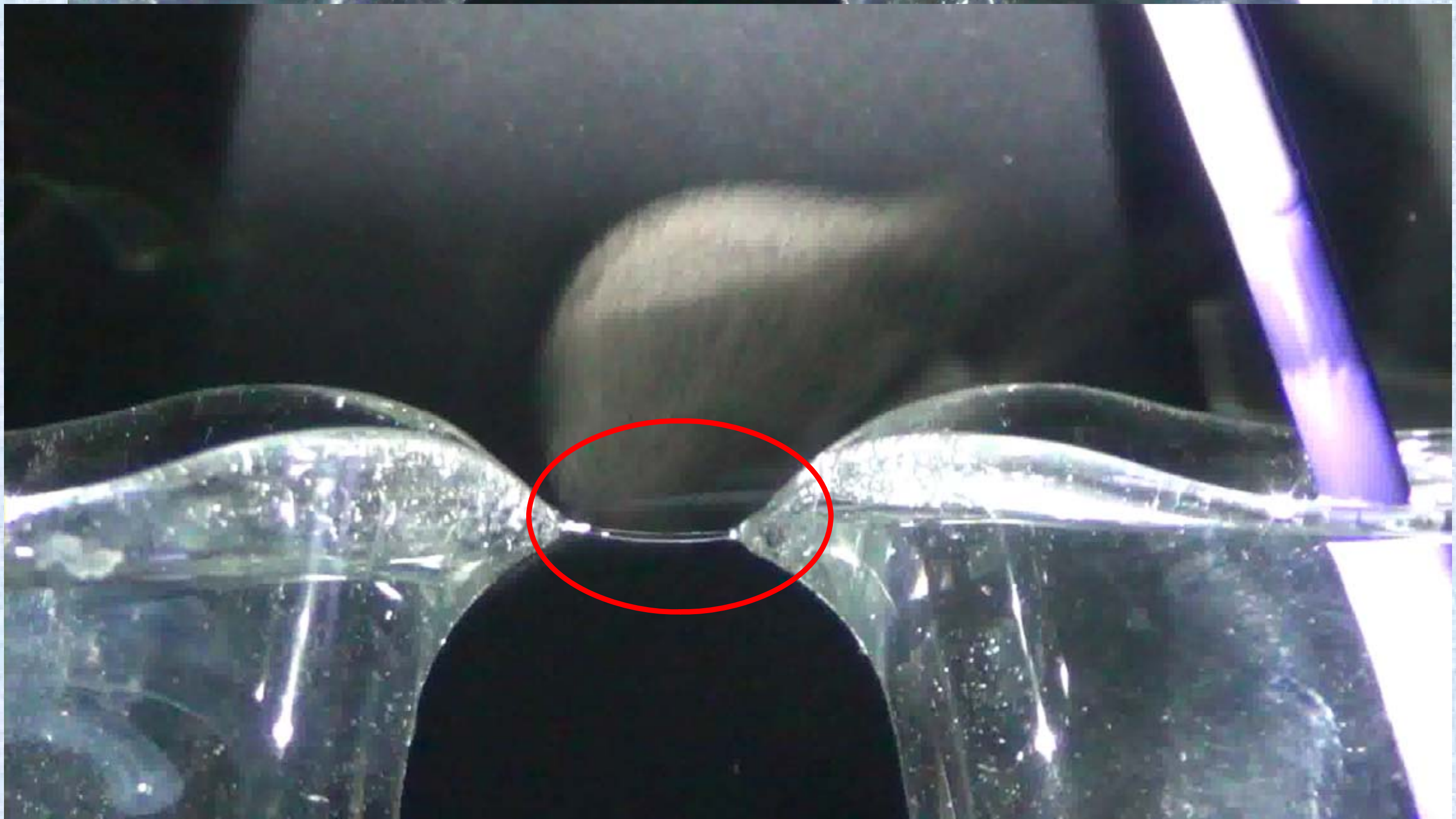
Evaporation

- Evaporation



Jets

Ion jets



Liquid flow in beakers

- Liquid flows in beakers when ions are present
- Liquid flows mainly in direction of anode, because negative ions are massive

Conclusion

- In case of high voltage, between the beakers appears a liquid bridge

- The main factors of fluid bridge stability are:
  1. **Electric forces**
  2. **Surface tension of liquid**
  3. **Molecular structures**

- Electric field and surface tension forces are needed for bridge not to be torn.

- Experimental and theoretical results coincide quite well

- There are signs of molecular structures

- Observed liquid bridge oscillations

Thank you for attention!

Reference

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2. D.A. Douglass, R. Thrash. **Sag and Tension of Conductor**. Taylor & Francis Group, LLC. 2006 .

3. A. Aerov. **Why the Water Bridge does not collapse**, Phys. Rev. E 84 (2011) 036314