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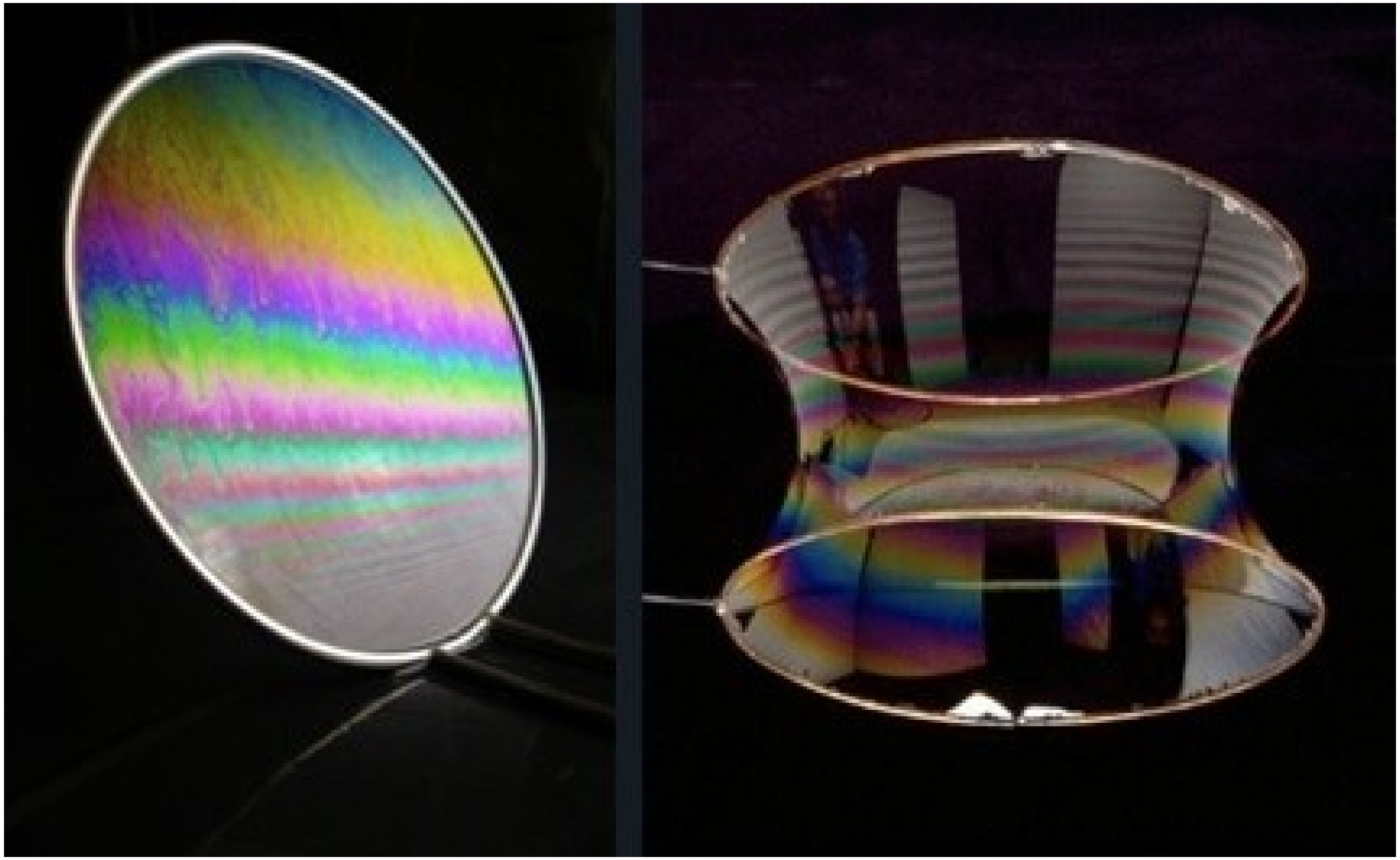
# №4. Soap film

# GEORGIAN Team



**Create a soap film in a circular wire loop. The soap film deforms when a charged body is placed next to it. Investigate how the shape of the soap film depends on the position and nature of the charge.**

# Presentation Plan

## 1. Description of soap film

- Structure of soap film
- Adding glycerin

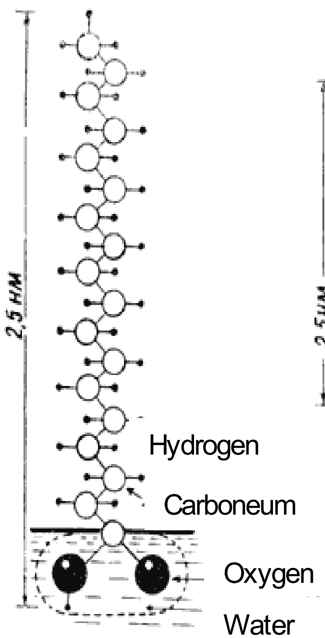
## 2. Experiment

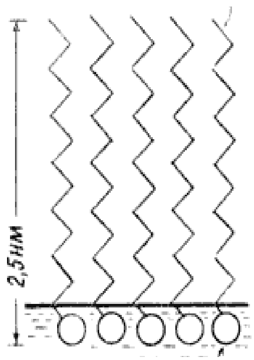
- Description of experiment
- Different shapes of charged bodies
- Grounding
- Phenomena, observed during experiments

## 3. Estimations and discussions

- Interaction of film and charged ball
- Film in uniform electric field
- Interaction of film and charged nail; electric wind
- Interaction of film and small-headed charged body
- Discussion on different polarity discharges

# Structure of soap film



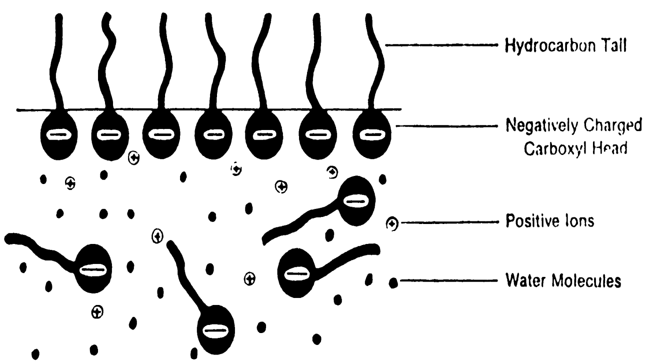

Soap film is formed by **Surface Active Agents (Surfactants)**

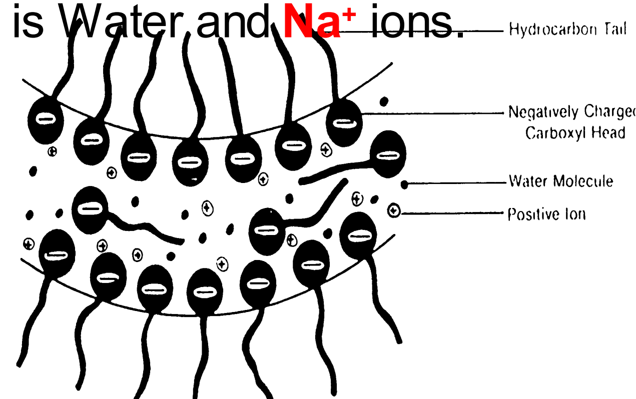
Two layers of soap molecules, between which is water.
The depth of this layer is ~ 50Å÷2x10$^5$Å , where Å = 10$^{-10}$.

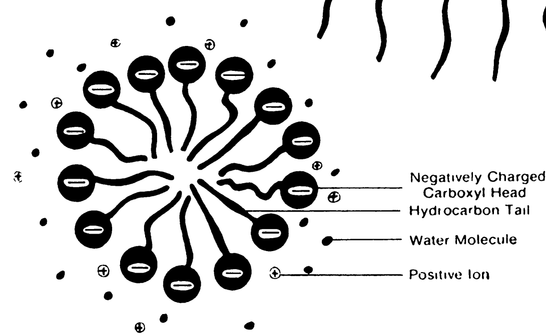
Soap molecule is divided into positive **$Na^+$** and negative **$C_{17}H_{35}COO^-$** ions.

**Negative ions** collect on the surface of film and they make **surface structure**

f film there is Water and **$Na^+$** ions.



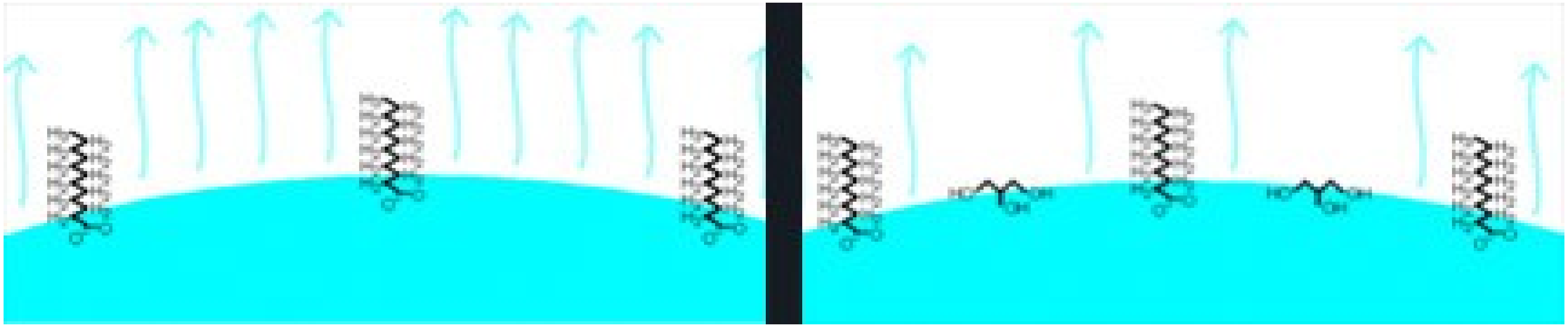




**Soap molecules:**

1. **Make a surface structure of soap film.**
2. **Decrease evaporation of water.**
3. **Decrease surface tension.**

# Adding the glycerin



Without glycerin

With glycerin

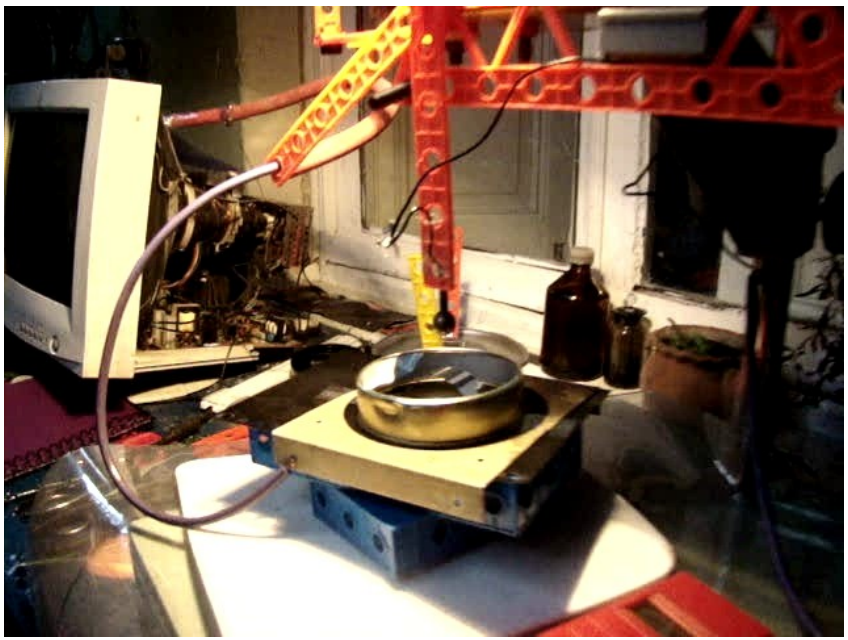
1. Glycerin decreases the evaporation of water from surface.

3. Glycerin adds more freedom to motion of molecules, because now they are turning around glycerin and not around other soap molecules.

So, due to glycerin soap film gets "extra duration of life" and also becomes more elastic.

# Experiment

## Description of the experimental device

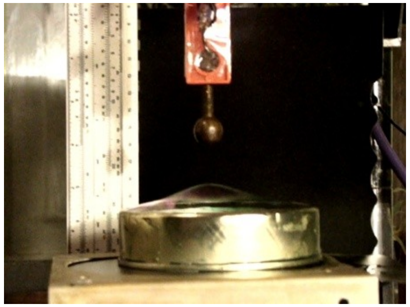


- Voltage source: an old CRT monitor, which provides the **27 000 volts**.
- Electrodes of different forms
- Different distances between electrodes and soap film.
- Metal loop; grounded and not grounded
- Dielectric loop.
- Changing poles
- With glycerin and without it.

**Description of device (video)**

# Charged Sphere

- **With glycerin the film was more stable.**



without glycerin 1(video)

with glycerin 1 (video)

- Larger the distance $d$ between sphere and film - **less the influence (deformation).**
- In case of $d$~5 cm, the height $h$ of film deformation in the center was up to **1 cm** and the film **remained stable.**

stable (video)

- For small $d \sim h$ , the stable state did not occur. **Film contained to stretch, discharge developed and film exploded.**

# The flat charged body

- By the flat charged body the film deformation was larger.

The flat charged body (video)

# Approximately Uniform field.

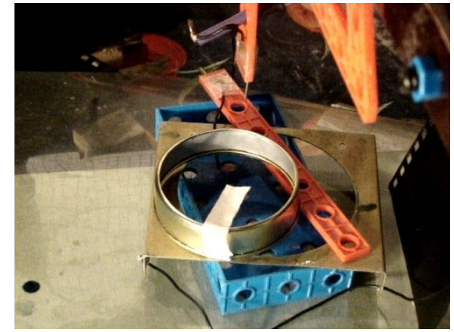
- To obtain the uniform field we used 2 parallel large lids.
- The bottom lid was grounded while the top was under the high voltage.
- The film was formed on a plastic ring.
- **Significant deformation did not occur. It just was torn in some time.**

# The charged body of a needle form

In case of charged nail. The soap film did not stretch out, but the dip was formed, as if there blew the wind from above.

nail 1 (video)

nail 2 (video)



nail and paper (video)

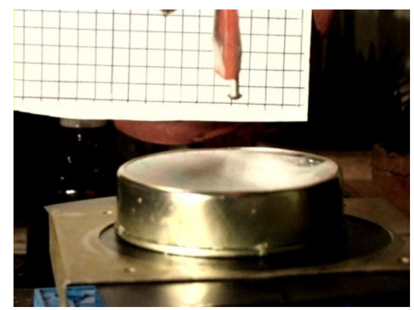
***Test of wind by paper***

# The charged body with a small head.

- In this case both - the "dip" and the "hill" are formed.

head 1

head 2



# Without grounding

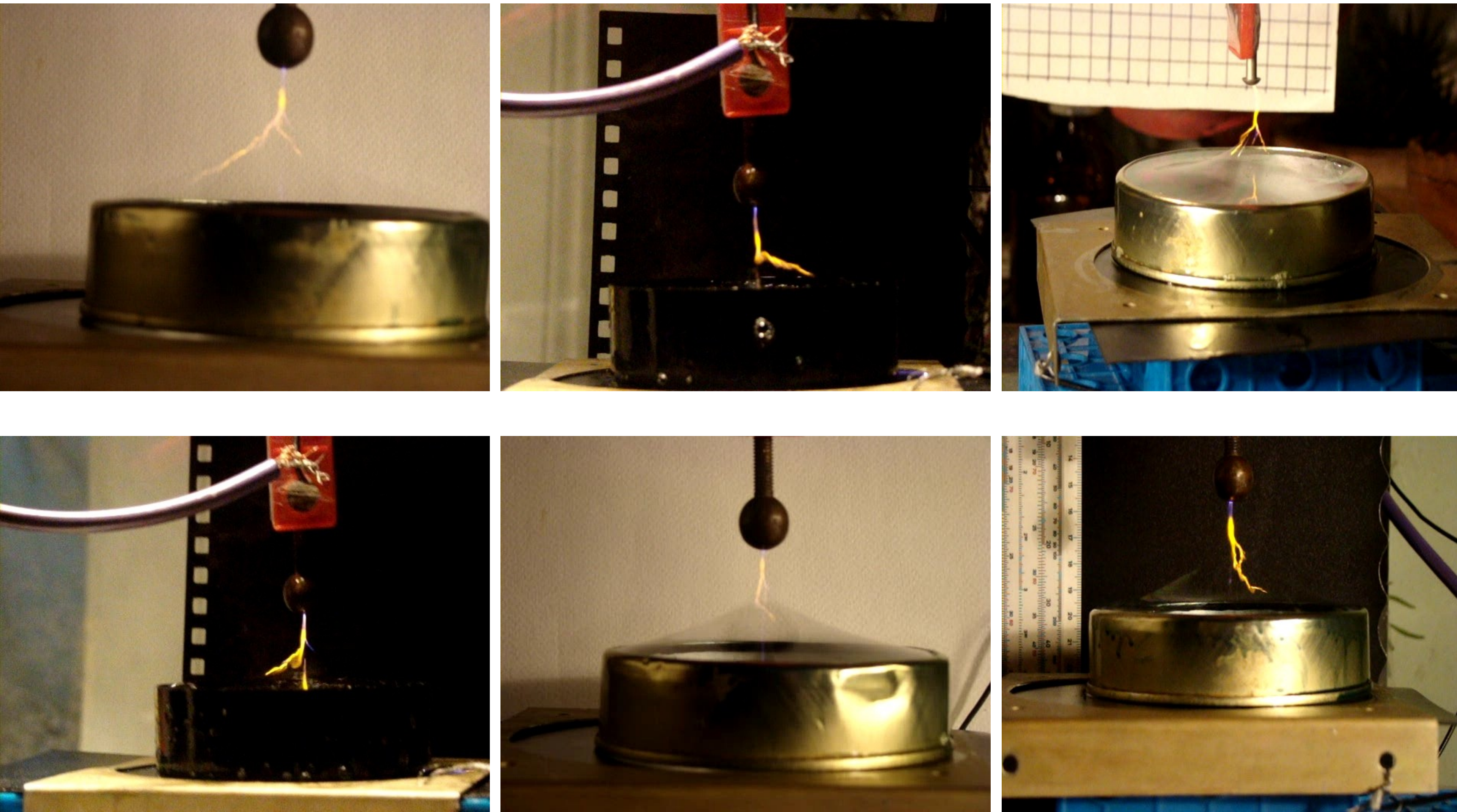
Without grounding stretch of the film was significantly less

without grounding

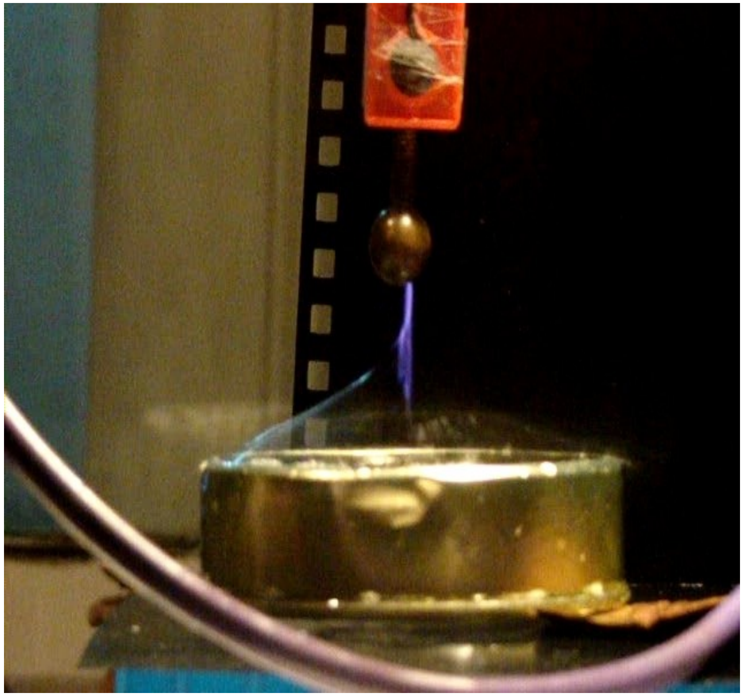
# Change of poles / shape and color of discharge

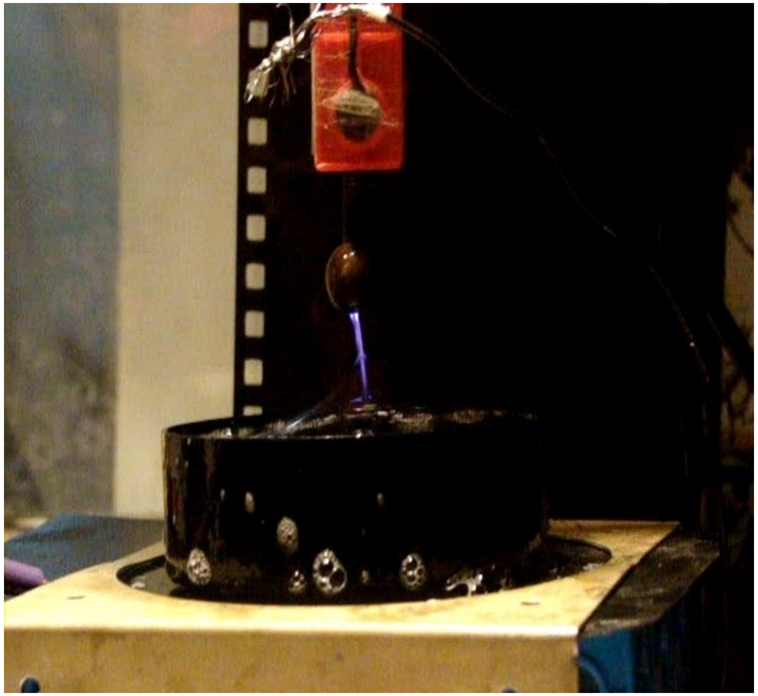
Change of the poles the affects the shape and the color of discharge.
Spark is dependent on the signs of electrode and of the film.

When electrode was charged **positively**, **discharge was** **spread and yellow**



When electrode was charged negatively, discharge was bluish and straight





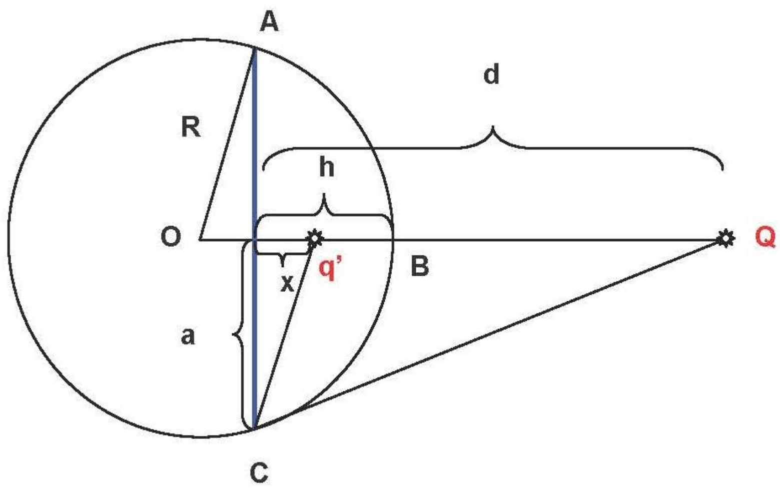
# Explanations and evaluations

## a) Interaction of film with the charged sphere

- The electric force is balanced by the surface tension force ;
- The surface tension force is calculated by means of Laplace equation;
- The force between the charge and the film is calculated using "electrostatic image method";
- Equating the electric and the surface tension forces.
- Using the approximation, when the deformation is much less than the loop radius and distance to charged sphere;

## The method of electrostatic image .

## Electric force




- External field redistributes the charges on the film.
- The film surface is equal-potential.
- Interaction between the charge and the grounded sphere film may be "effectively" presented as the interaction between two point charges.
- The value and the place of "effective" charge must provide equal potential of film surface

- The film is **sphere segment** ABC of the height $h$
- AC – the loop with radius $a$.
- $Q$ – the external charge, at the distance $d \gg h$
- $q'$ – the "effective" charge at the distance $x$ from the loop.

Condition of $\varphi_B = \varphi_C = 0$ (grounded film) leads to the following values:

$$x = \frac{2a^2 h - a^2 d + h^2 d}{a^2 + 2dh - h^2} \qquad (1)$$

$$q' = -Q\frac{a^2 + h^2}{a^2 + 2dh - h^2} \qquad (2)$$

And the effective force

$$F_k = kQ^2 \frac{(a^2 + h^2)(a^2 + 2dh - h^2)}{4(d-h)^2 (a^2 + dh)^2} \qquad (3)$$

## The surface tension force $F_l$.

Let us use Laplace formula and formula of the sphere segment area

$$S = \pi\,(a^2+h^2).$$

According the Laplace formula $P_l = 4\,\sigma_0 / R$ and taking into account, that

$$R = \frac{a^2 + h^2}{2h}$$

we obtain

$$p = \frac{4\sigma_0}{R} = 4\sigma_0\,\left(\frac{2h}{a^2 + h^2}\right)$$

If one writes down $F_l = pS$, **it is possible to obtain, that the force of surface tension is**

$$F_l = 8\pi\sigma_0\,h \tag{4}$$

## Balance of Electric and Surface tension forces

Using the condition of(3) c

$$kQ^2 = \frac{32\pi\sigma_0\,h\,(d - h)^2(a^2 + dh)^2}{(a^2 + h^2)\,(a^2 + 2dh - h^2)} \tag{5}$$

# Approximation $h << a; h<<d.$

In this case the formulae (1), (2), (3), (5) transform to:

$$x \approx 2h - d \qquad (6)$$

$$q' \approx -Q \qquad (7)$$

$$F = kQ^2/(4d)^2 \qquad (8)$$

$$kQ^2 = 32\pi\sigma_0 hd^2 . \qquad (9)$$

from (9) we can obtain **dependence of $h$ on $Q$ and $d$**

$$h = \frac{k}{32\pi} \cdot \frac{Q^2}{\sigma_0 d^2} = \frac{1}{128\,\pi^2\,\varepsilon_0} \cdot \frac{Q^2}{\sigma_0 d^2} \qquad (10)$$

Let's calculate ***h* for our experiment**.

(Graph is given on the next slide)

For 1 cm radius charged sphere, at the potential $\varphi$ **= 27 000 v,**

$$Q = C\varphi = 4\pi\varepsilon_0 r \cdot \varphi \approx 3 \cdot 10^{-8}\ Coulomb$$

taking into account $\sigma_0 \approx 25 \cdot 10^{-3}\ n/m,$ **for the distance** $d = 5\ cm$ from (10) we have:

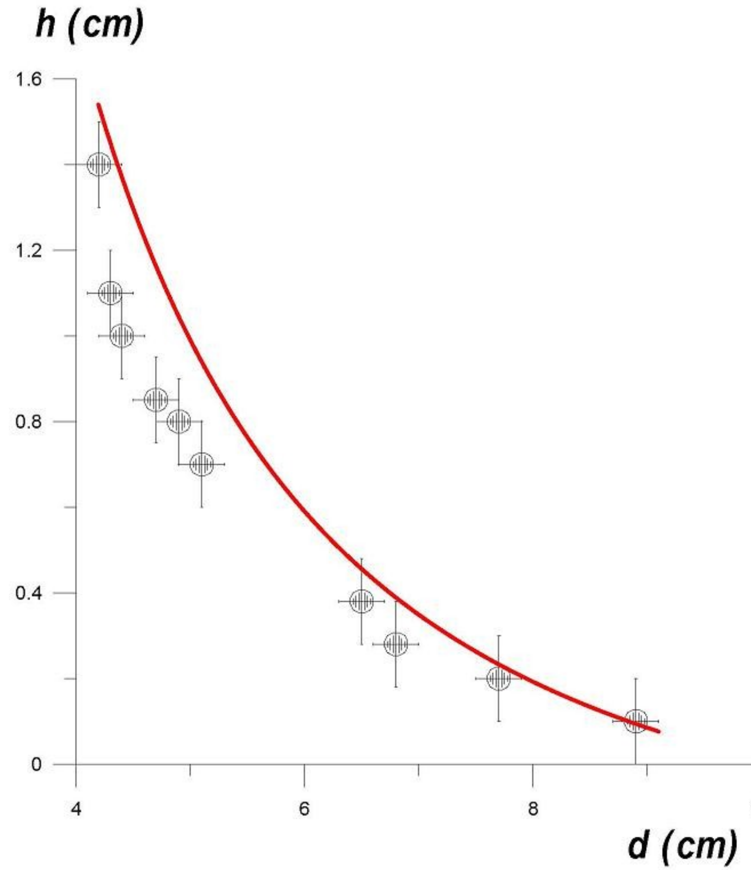
$$h \approx 1\ cm$$

which is quite near to our experimental results.

The dependence h (d)

for the stable states:

(experiment - points; theory - curve))




**From the 4-th and 3-rd formulae :**

$$F_l \sim h \qquad ; \qquad F_k \sim 1/(d-h)^2 .$$

**If** $h \ll d$, then the $F_l$ increase with $h$ **faster, than** $F_k$. So the **stable equilibrium** is reached.

**If** $h \sim d$, then $F_k$ increases with $h$ **faster, than** $F_l$ so **the film stretches and bursts.**

## b) Behavior of film in uniform field

In uniform field the film did not stretch, due to symmetry.

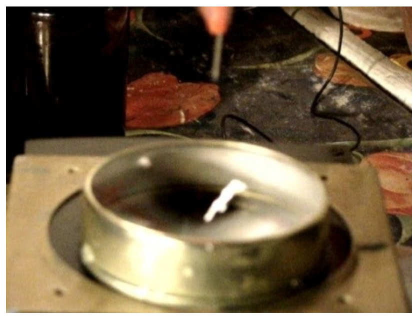
In strong field film is torn by forces acting on the positive and negative charges.

## c) Interaction of the film with charged nail

In this case the observed dip (instead of a "hill") was caused by so called "electric wind", which blow rather strong and this strength was greater than the strength of attraction.

<u>**electric wind**</u>

nail 2



counter

## d) Interaction of film with small headed charge

In this case the observed behaviour reveals both processes - the electric wind and the attraction towards electrode.

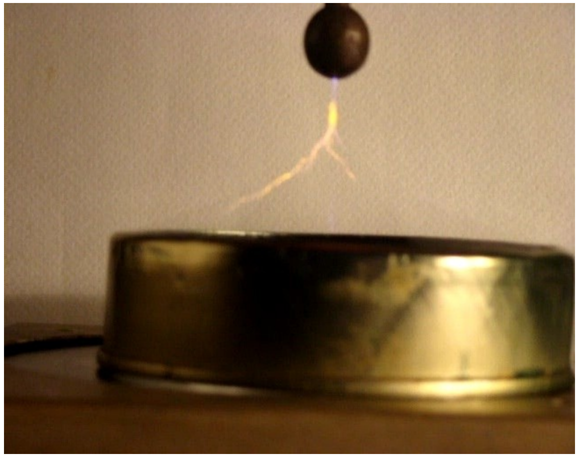
Head2

# e) Asymmetry with respect to change of poles

At high temperatures the atoms emit the electromagnetic waves (photons). Frequency of emitted light depends on the transition energy between two levels in atom.

$$E_{photon} = h\nu$$

Where ***h*** **–** is Planck constant, and $\nu$ - frequency of emitted light.

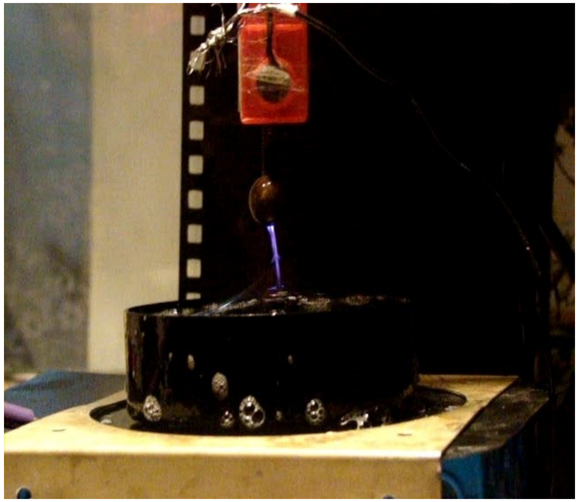


***Na*** **emits yellow light**, while ***N*** **- emits bluish - lilac light**.

So if electrode is charged **negatively**, then the atoms of **Nitrogen** (which are contained in air) are emitting the light.

In case of **positively** charged electrode -**Sodium** (***Na)*** atoms are emitting.

Negative external charge accelerates the electrons toward the film. The accelerated electrons strike the atoms ***N*** **of air** and cause their bluish-lilac emission.



Positive external charge accelerates heavy ions of air towards the film. These ions hit the film and punch out of it the positive ions $Na^+$.

Also in this case $Na^+$ is attracted to negative ions of soap (which form film structure). So discharge becomes more "spread".

The upper part of the burst is blue, while the yellow region is under the level which can reach $Na^+$.

# Conclusion

- Soap Film interactions with charged bodies were studied
- Different shapes of charged bodies were tested
- Resulting film deformations were examined
- Film deformation strongly depends on:
  - Shape of charged body
  - Charge value
  - Distance from the film
  - Grounding of loop on which the film is formed
  - Film consistency
- Discharge Asymmetry with respect to change of poles was observed

# Thank you for attention!