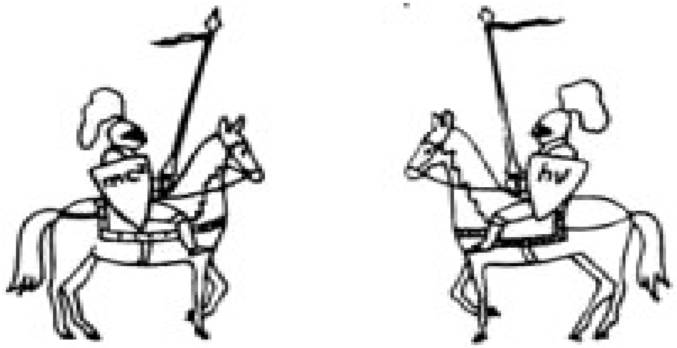

IYPT 2010

Problem #17

Kelvin Dropper

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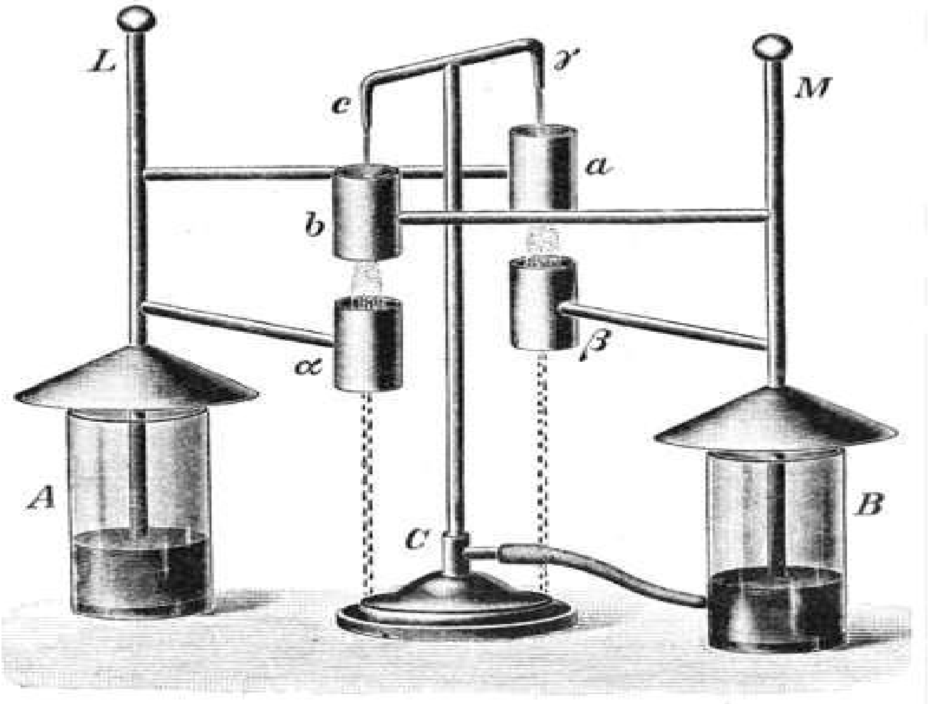
Problem

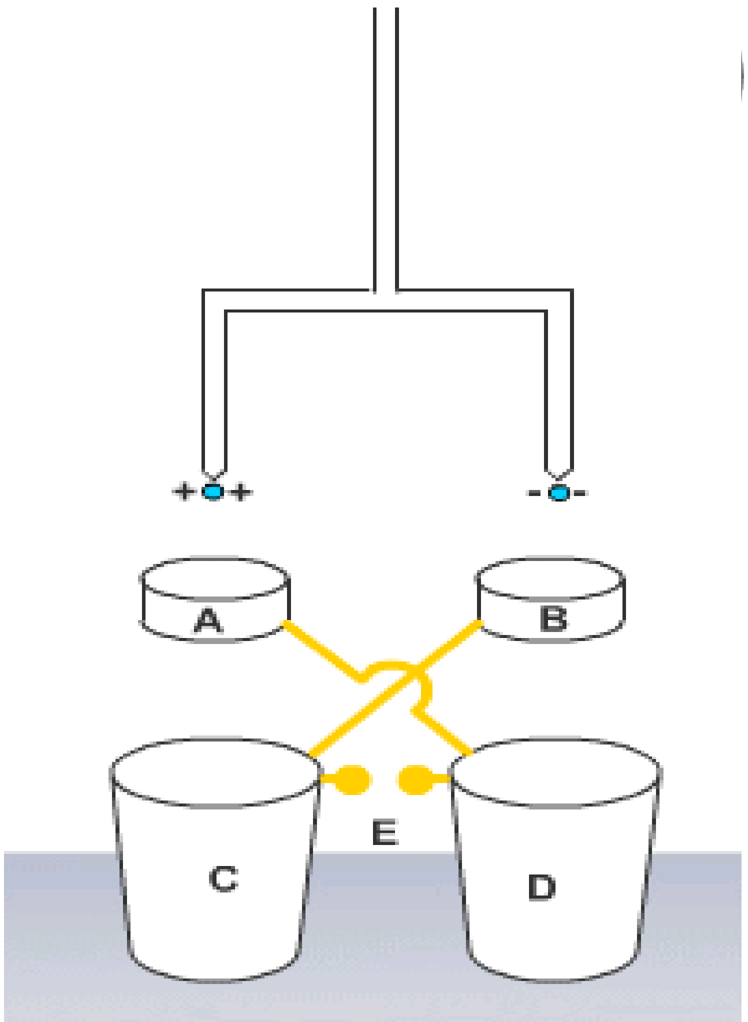


Construct Kelvin's dropper. Measure the highest voltage it can produce. Investigate its dependence on relevant parameters.

Plan of presentation

- **Kelvin dropper's working principles**
- **Description of device and the first experiment**
- **Results of the experiment**
- **Evaluations:**
    - Speed of voltage growth
    - The possible accumulated charge and voltage in ideal case
    - Factors affecting the result
- **Experiment with optimised parameters**
- **Conclusions**

Working Principles



- ✓ Existence of H+ and (OH)- ions in water
- ✓ Violation of symmetry as a result of fluctuation
- ✓ Separation of ions under the influence of other charges
- ✓ Electric conductivity of water
- ✓ "Positive feedback"
- ✓ Water jets split into drops in the very vicinity of the inductor's center
- ✓ Accumulation of charged drops in collectors due to gravitation force

Description of device and the first experiment

(experiment)

The result of experiment

In first experiments, we evaluated the voltage by discharge gap which was ~ 1 cm. At ordinary conditions it corresponds to:

U ~10 000 V – 30 000 V

The results of experiment strongly depend on environment parameters.

Evaluations

Velocity of voltage growth:

Due to positive feedback the speed of voltage growth is proportional to the voltage itself:

$$\frac{dU}{dt} = \alpha U$$

from here

$$U = U_0 e^{\alpha t} \qquad (1)$$

i.e. both the voltage and correspondingly the charge are increasing exponentially.

Let's consider coefficient α :

$$\alpha \sim \frac{1}{C + C_{Load}} \cdot \left(nC_{Drop} - \frac{a}{R_{Ground}} - \frac{b}{R_{(1\leftrightarrow 2)}} \right) \qquad (2)$$

C **– is the joint capacity of the collectors and inductors;**
C_{Load} – capacity of voltmeter and other "loads";
C_{Drop} – capacity of water drop;
n **– the number of drops, falling into collector in unit of time;**
R_{Ground} – *Resistance between the generator and ground*, through which the parasit current flowes;
$R_{(1 \Leftrightarrow 2)}$ –resistance between the collectors. Through it as well the parasit current will flow.
a, b **– are the coefficients**

This expression was obtained via following considerations:

- Higher the capacity of the system - slower the increase of the voltage (for given speed of charge delivery);
- The "competition" between the accumulation of charge and its leek through the parasite currents.
- Charge accumulation rate is proportional to the number of drops per second and to the charge of each drop.
- Parasite currents are back-proportional to the Resistance (insulation) of the system.
- If

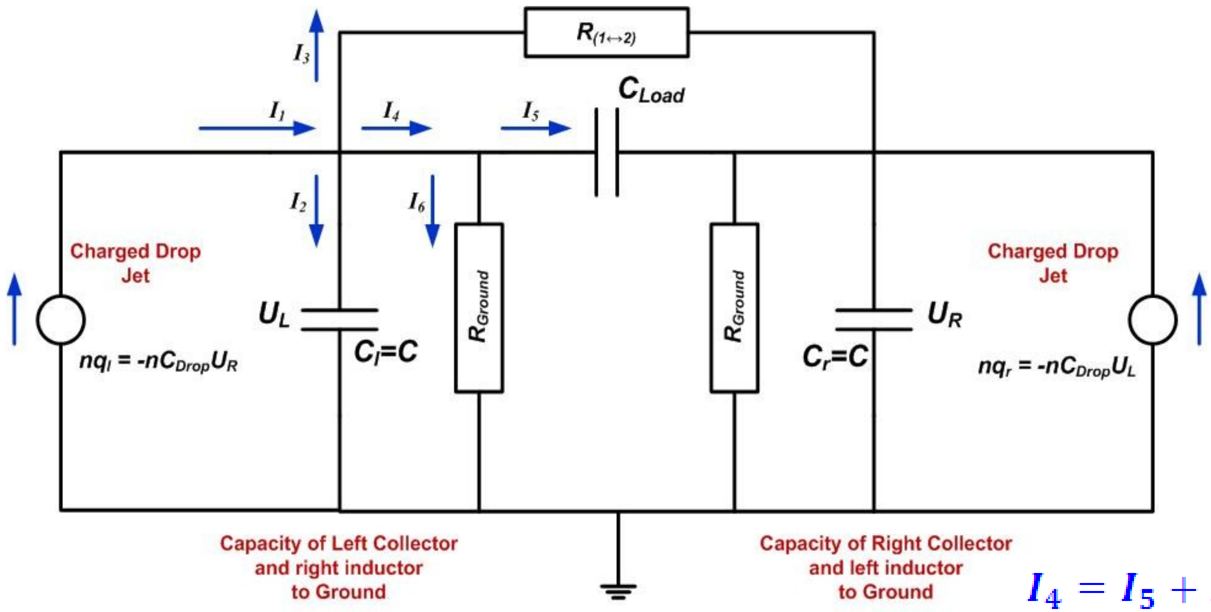
$$nC_{Drop} < \frac{a}{R_{Ground}} + \frac{b}{R_{(1\leftrightarrow 2)}}$$

accumulation of charge will not take place.

- according to dimension representation:

  $[C] = L^{-2}M^{-1}T^{4}I^{2}$; $[R] = L^{2}MT^{-3}I^{-2}$ => $[C][R] = T$

Derivation of Voltage growth formula



Kelvin Dropper equivalent scheme

$$I_1 = I_2 + I_3 + I_4$$

$$I_1 = -nC_{Drop}U_R$$

$$I_2 = C\frac{dU_L}{dt}$$

$$I_3 = \frac{U_L - U_R}{R_{Load}}$$

$$I_4 = I_5 + I_6 = \frac{C_{Load} \cdot d(U_L - U_R)}{dt} + \frac{U_L}{R_{Ground}}$$

- ***U_L* - Potential of "Left Collector and Right Inductor" to Ground**
- ***U_R* - Potential of "Right Collector and Left Inductor" to Ground**
- ***C_l=C_r=C* , where *C_l* is joint Capacitance of "Left Collector and Right Inductor" to Ground and *C_r* - the same for "Right"**
- ***Charge of drops: $q_r = -C_{Drop}U_L$ and $q_l = -C_{Drop}U_R$ where C_{Drop} is "effective drop capacitance" – coefficient of proportionality.***

From the sum of currents for Left side

$$\left(-nC_{Drop}+\frac{1}{R_{Load}}\right)U_R-\left(\frac{1}{R_{Load}}+\frac{1}{R_{Ground}}\right)U_L=C\frac{dU_L}{dt}+\frac{C_{Load}\cdot d(U_L-U_R)}{dt}$$

From the sum of currents for Right side

$$\left(-nC_{Drop}+\frac{1}{R_{Load}}\right)U_L-\left(\frac{1}{R_{Load}}+\frac{1}{R_{Ground}}\right)U_R=C\frac{dU_R}{dt}+\frac{C_{Load}\cdot d(U_R-U_L)}{dt}$$

From the symmetry $U_L=-U_R$ or $U_L=U_R$

A) For $U_L=-U_R$ the voltage growth equation:

$$(C+2C_{Load})\frac{dU_L}{dt}-\left(nC_{Drop}-\frac{2}{R_{Load}}-\frac{1}{R_{Ground}}\right)U_L=0$$

And the similar for U_R

B) For $U_L=U_R$

$$C\frac{dU_L}{dt}+\left(nC_{Drop}+\frac{1}{R_{Ground}}\right)U_L=0$$

And the similar for U_R

The complete solution is the sum of solutions (A) and (B)

$$U_L = A \cdot e^{\alpha t} + B \cdot e^{-\beta t}$$

Where

$$\alpha = \frac{1}{(C + 2C_{Load})}\left(nC_{Drop} - \frac{2}{R_{Load}} - \frac{1}{R_{Ground}}\right)$$

and

$$\beta = \frac{1}{C}\left(nC_{Drop} + \frac{1}{R_{Ground}}\right)$$

It is clear, that solution (B) vanishes exponentially,
While for solution (A) for the voltage growth it is necessary, that

$$nC_{Drop} > \frac{2}{R_{Load}} + \frac{1}{R_{Ground}}$$

This means good insulation $R_{Load} \rightarrow \infty$ $R_{Ground} \rightarrow \infty$

And **large** drop-charge jet nC_{Drop} .

The possible accumulated charge and voltage in ideal case

Charge

- In normal conditions 1 liter of water contains $\sim 10^{-7}$ moles of ions, or $N \sim 10^{16}$ ions.
- The charge of each ion is $e = 1.6 \cdot 10^{-19}$ *Coulomb*
- If all of ions will accumulate in collectors, the whole charge will be

$$Q = N \cdot e \sim 10^{-3} \text{ Coulomb} \qquad (3)$$

(**Though it is obvious, that this charge is huge, and unreal**)

Voltage

The voltage between the two charged cylinders:

$$U = \frac{\sigma}{\pi \varepsilon \varepsilon_0} \ln \frac{(d - R)}{R} \qquad (4)$$

Where: $\sigma = Q/h_{cyl}$ - is charge per unit of cylinder height

d - distance between the cylinders axis of symmetry

R - radius of cylinder ; d > 2R

If : $d=0.3m$, $R=0.05m$, $\varepsilon=1$, the hight of collector $h=0.2m$, while from (3) we have $Q = N \cdot e \sim 10^{-3} C$, i.e. $\sigma = 5 \cdot 10^{-3}$ C/m, so we obtain

$$U \approx 5 \cdot 10^{8} V. \qquad (5)$$

(it is in case, if all ions of 1 Liter of water were separated).

It is obvious that, this voltage is also huge and unreal.

From (4) we see, that the larger the distance between the collectors - the higher voltage is achieved.

The factors affecting the result

Preventing:

a) Electrostatic Corona discharge
b) Electric forces affecting the water drops
c) Humidity of environment
d) "Parasite" currents

Supporting:

a) Increase of the number of ions in liquid
b) Increase of the number of drops per second

a) Electrostatic Corona discharge

- **Electrostatic discharge in air takes place when the voltage of electric field reaches 10 - 30 kV/cm.**
- **Obtaining higher voltage will be possible in the case of covering the parts with good dielectrics (insulators).**
- **On the other hand, at high humidity discharge takes place at smaller voltage as well.**

b) Forces affecting the water drops

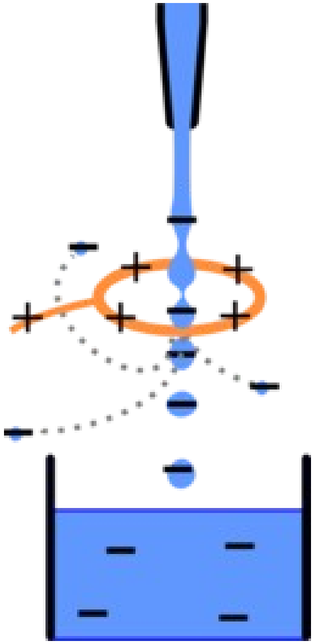
If 1 Liter of water contains 10^{16} ions, then in 1 mm³ drop there will be $n \sim 10^{10}$ ions.
If in 1 drop there are only ions of the same sign, then the charge will be $q = ne \sim 10^{-9}$ C.

The gravitation force, affecting 1 mm³ drop

$$F_{Grav} = 10^{-5}\ N$$

If the distance between the drop and collector (or inductor)~0.1 m, then the electric force affecting the drop will be

$$F_{El} \sim k\frac{qQ}{10^{-2}} \sim 10^{10} \cdot \frac{10^{-9}Q}{10^{-2}} \sim 10^{3}\ Q \qquad (6)$$



from here one can see, that to prevent drop to fall into collector,

$$F_{Grav} < F_{El},$$

the charge must be $Q \sim 10^{-8}$ C. *This corresponds to voltage*

$$U \sim 10^{4}\ V$$

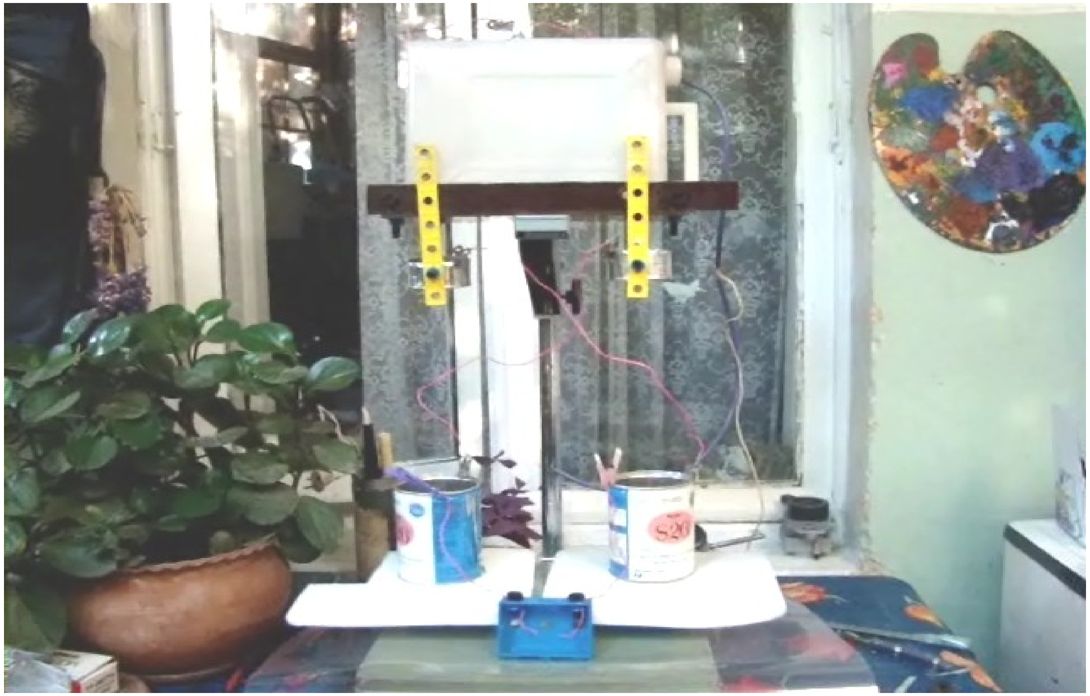
So we again obtain the tens of thousands volts.

In course of experiment we have seen the deviation of water streams from vertical, caused by electric fields.

(video of drop deviation)

c) Humidity of environment

The more Humidity - the less voltage.



d) "Parasite" currents (bad insulation)

When during the experiment the device was getting wet, there took place leak of the charge from collectors by means of so called "parasite" currents, and voltage decreases as well.

Experiments with different parameters

Taking into account all factors affecting above mentioned evaluations and results we carried out experiments changing the following parameters:

3. **Adding the salt to water**
4. **Increase of water jets** **(though providing their decay into drops)**
5. **Increase of the distance between the collectors**
6. **Making better the insulation of system**

Voltage was measured with the help of electrostatic voltmeter

1. **By addition of salt, generator starts its action much faster and provides higher voltage.**

- Due to Na^+ and Cl^- ions the final number of ions increases.
- Thus increases amplitude and probability of fluctuations.
- Increases charge accumulation speed as compared with speed of charge leak.

7. **Increase of water jet causes the speed of charge accumulation.**

- Water jet increase also increases charge accumulation speed as compared with speed of charge leak.

video : Increase of jet

1. **Increase of distance between the collectors enlarges the obtained voltage.**

- As we mentioned, we can see from (4) that the further the collectors, the more voltage is achieved.

- **Increasing the degree of insulation results in high voltage obtained**

- We also tried to replace the iron collectors with those, made of porcelain plates.

Fulfilling these 4 conditions and what is very important, improving the insulation, we get 30 000v voltage.

We measured the voltage with help of electrostatic voltmeter.

video cups **video 30 kv**

CONCLUSION

With help of Kelvin dropper it is possible to obtain tens of thousand volts voltage.

The result strongly depends on the surrounding conditions.

Obtaining high voltage is supplied by:

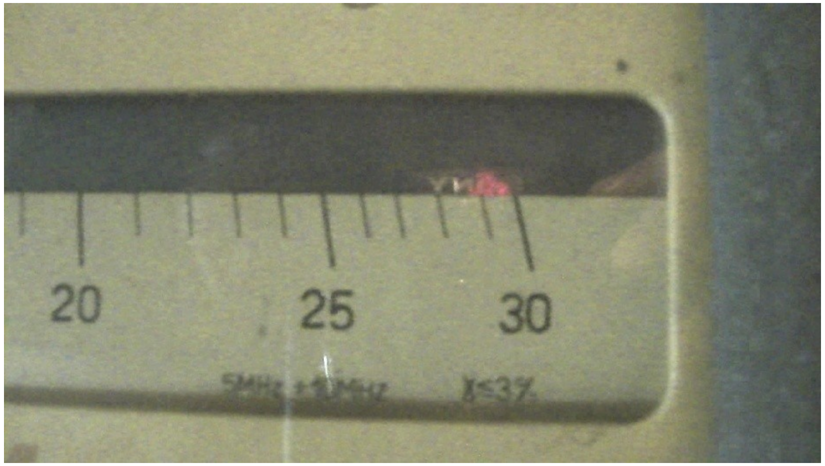
5.Insulation, as good as possible. May be locating the device ipon two tables, to separate the poles.

6.Making experiments in less humidity conditions.

7.Increase of jets of drops. May be usage of several droppers.

8.Adding more ions to water. (e.g. adding salt)

9.Increase of device dimensions.



We managed to obtain 30 000v voltage.

Thank you for attention!