

23rd IYPT Problem 17: Kelvin's Dropper



Franklin Liou, Jun-Yu Chu, Chien-Hua Pao

Concordia Middle School, Department of Physics National Chung-Cheng University

Abstract

Kelvin's dropper is a symmetrical device consisting of two identical rings and buckets. Each ring is cross connected to a different bucket, with identical water streams passing through the rings and into the buckets.

This device can make opposite charges accumulate on the isolated ring-bucket pairs, and is a self amplifying process, inducing more charge separation as the voltage climbs. However, there is a maximum voltage for each particular setup of the device, because electrical breakdown occurs when the electric field is too strong.

To reach the maximum charge, we found that the stream has to separate into droplets in the vicinity of the rings and the ring diameter needs to be small enough to induce a stronger electric field.

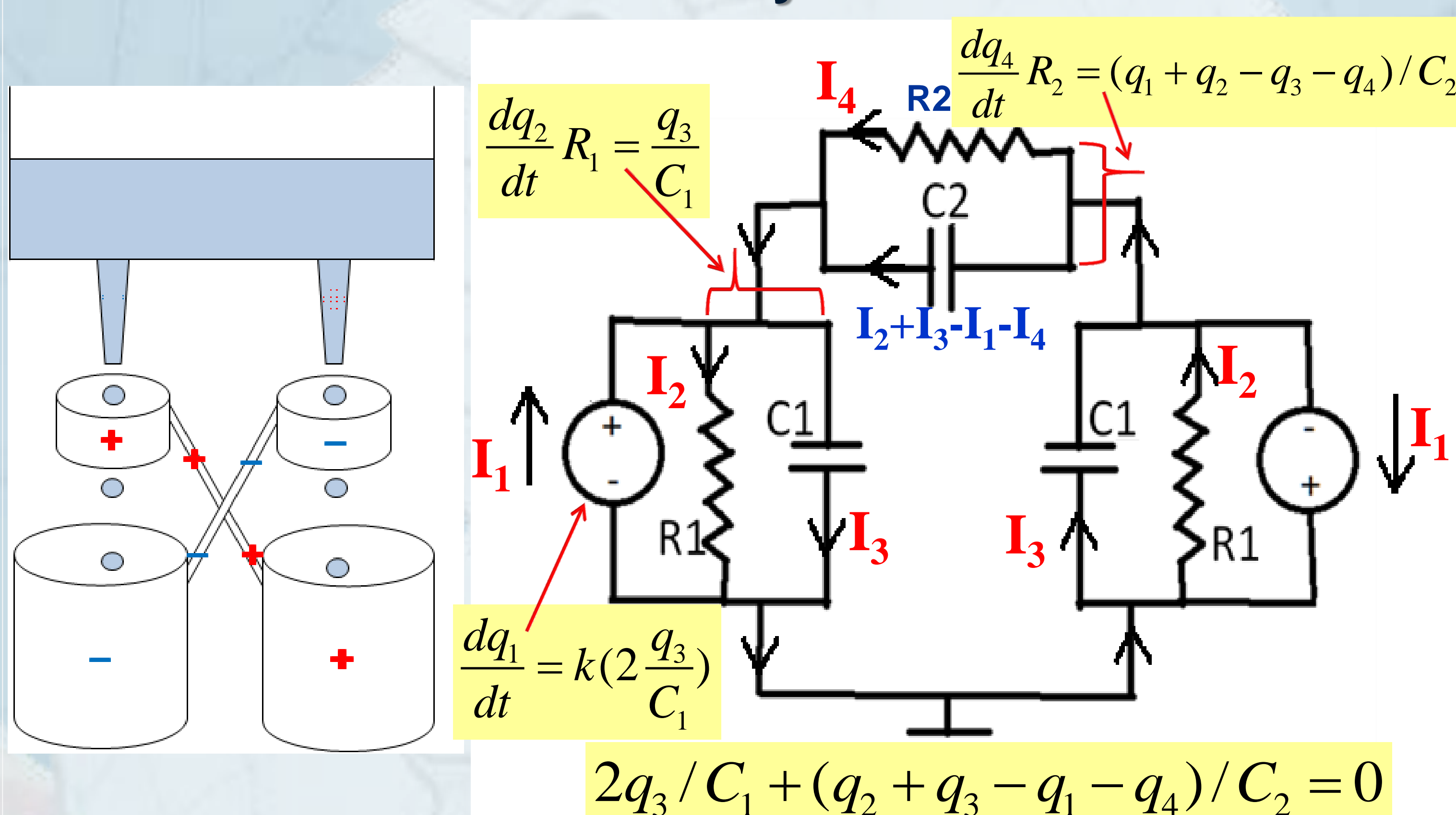
By analogy to a circuit, we find that the resistance between the ring-bucket system has to be larger than a critical value in order for the device to operate.

Experimental Setup



(a) Kelvin's dropper
(b) Rings of different diameter
(c) Static charge measuring device

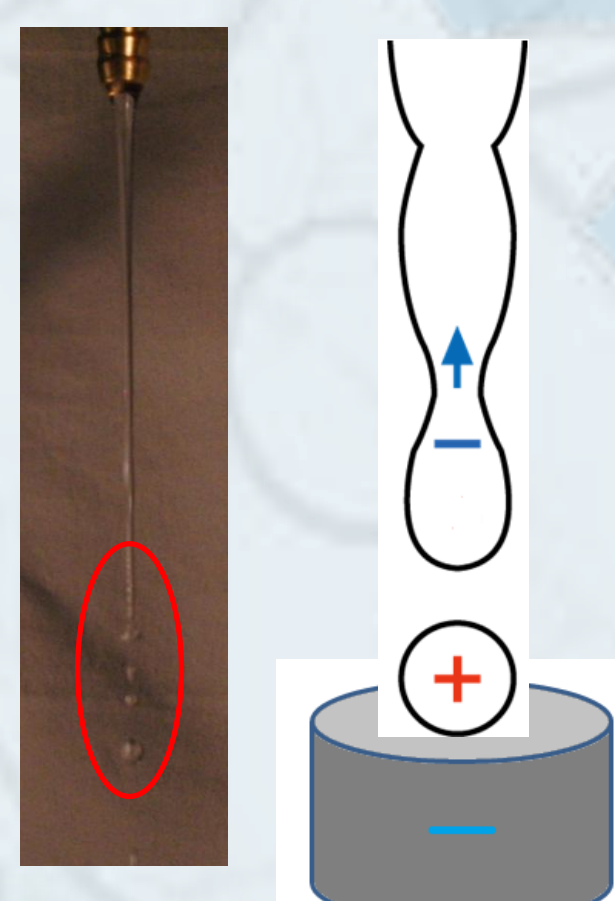
Theory



$$V = \beta V_0 \left(e^{\gamma(k - \frac{1}{R_2} - \frac{1}{2R_1})t} - 1 \right) \Rightarrow k > \frac{1}{R_2} + \frac{1}{2R_1}$$

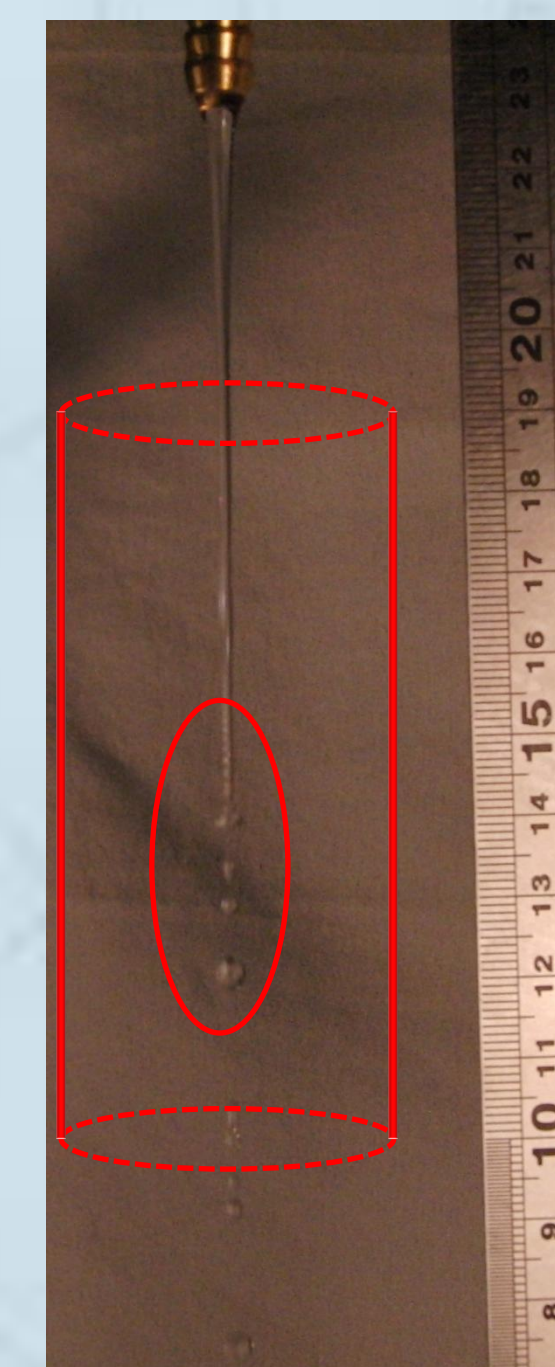
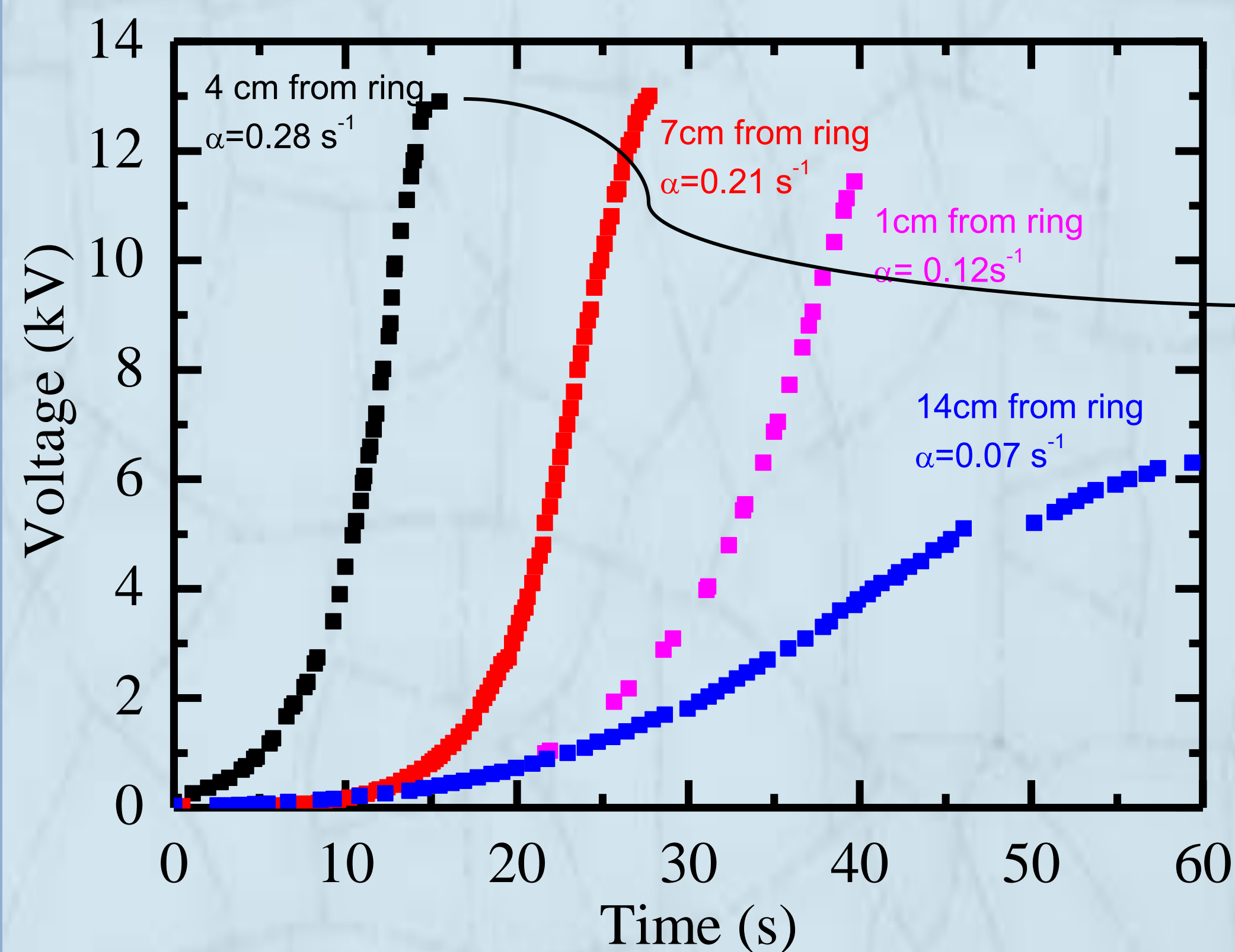
Exponential growth

When voltage exceeds a certain level, new paths are opened in the circuit to leak charge

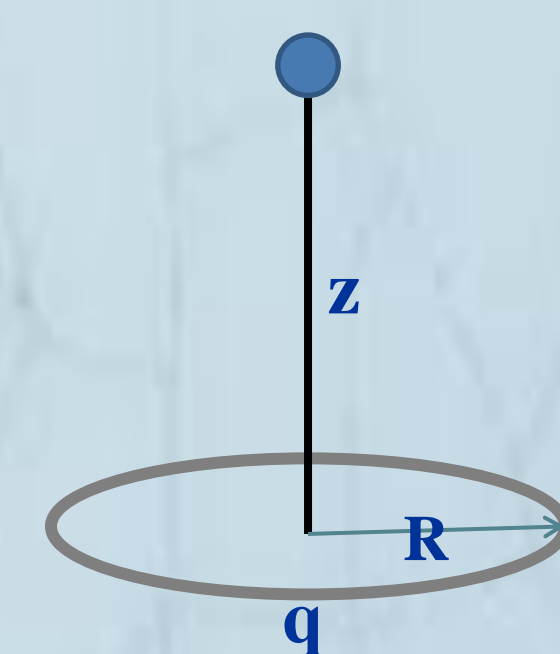
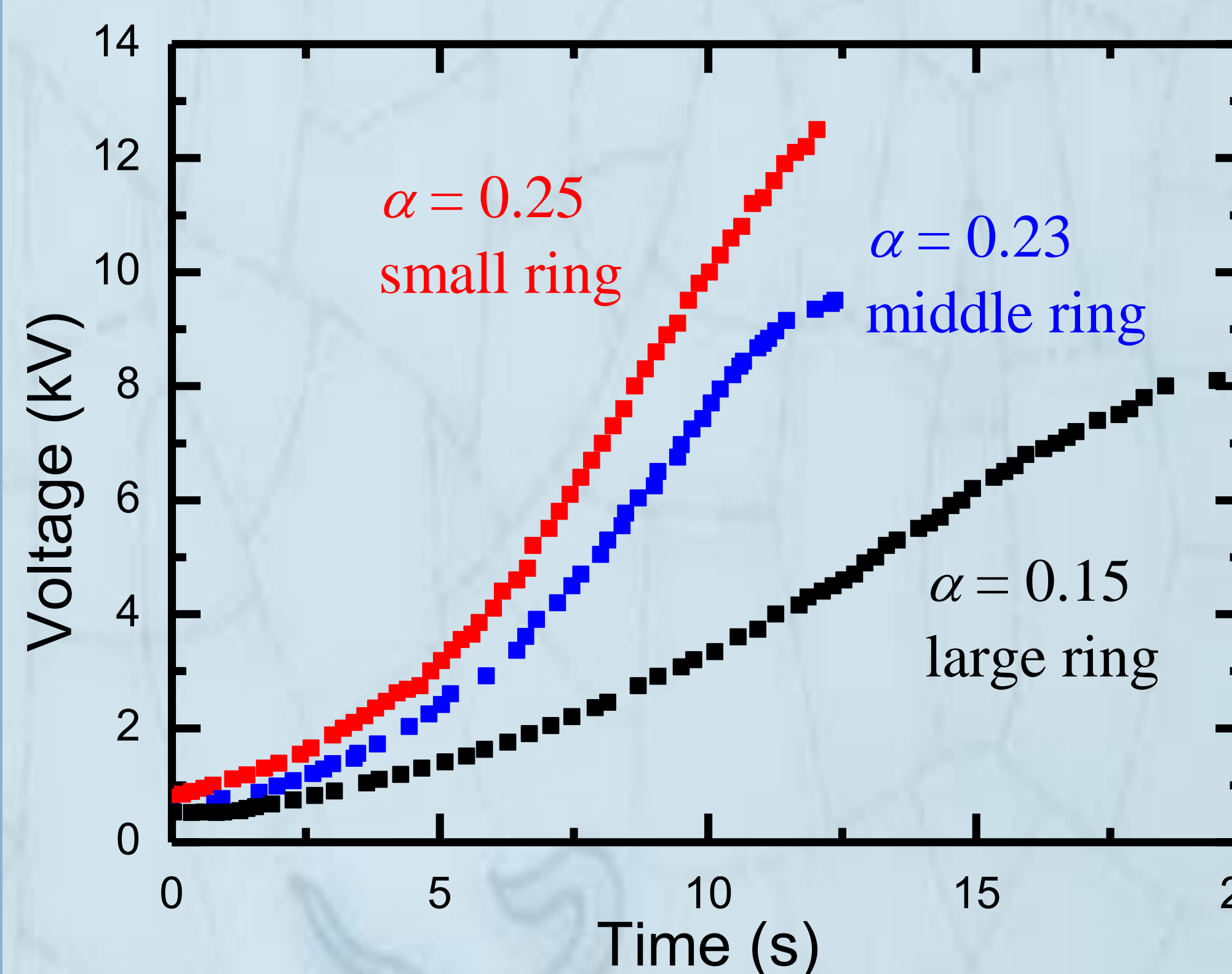


Result

Maximum voltage and ring position:



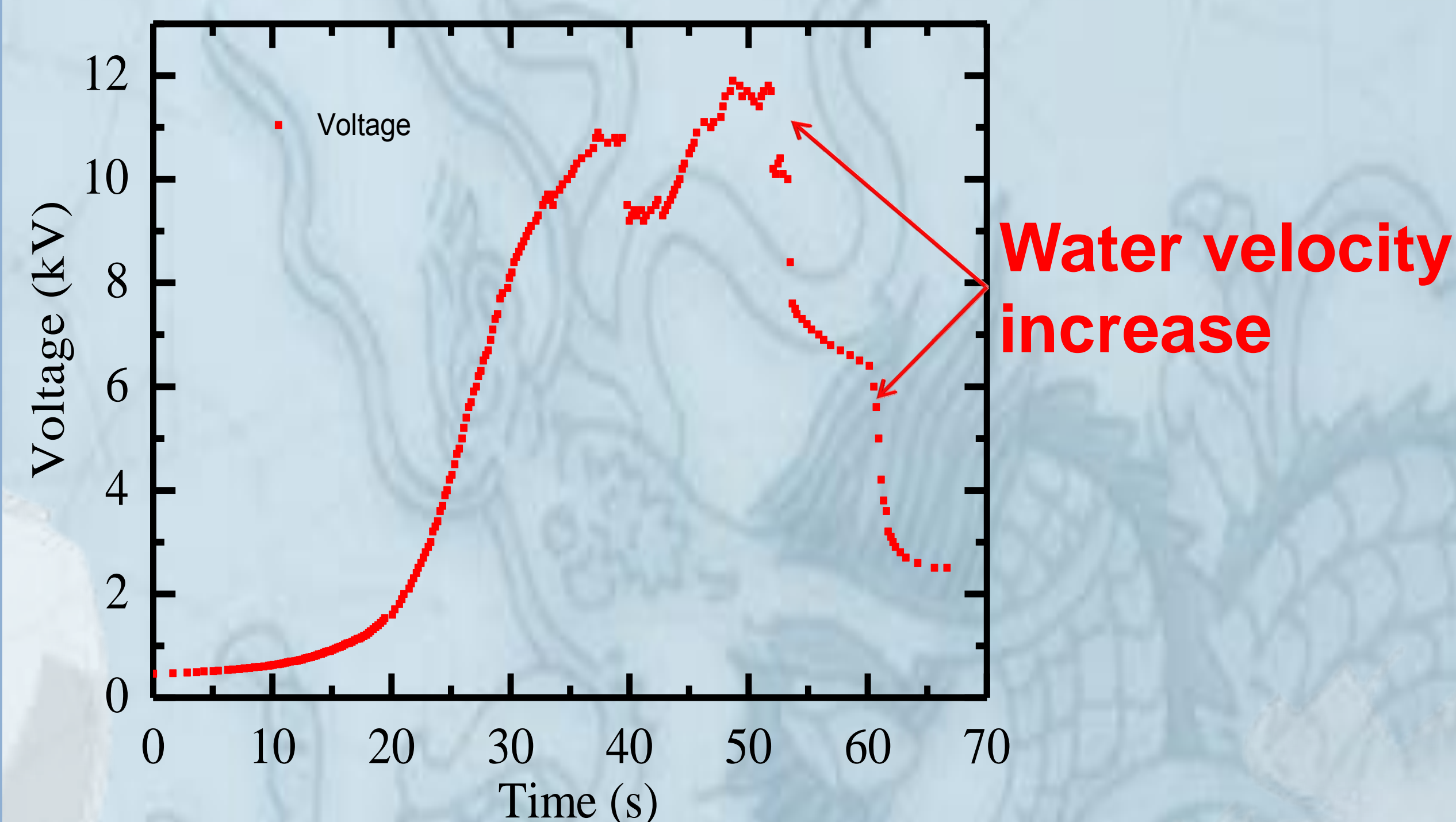
Ring diameter:



$$E = \frac{qz}{4\pi\epsilon_0(z^2 + R^2)^{3/2}}$$

$$R \downarrow \Rightarrow E \uparrow \Rightarrow Q \uparrow$$

Water velocity:



Conclusion

- Analogy to circuit shows that the linkage resistance must be lower than a certain critical value for Kelvin's dropper to charge up: Insulation is critical.
- Maximum voltage increases as ring is nearer to the droplet separation range
- Maximum voltage increases with smaller ring diameter

Reference

- [1] Vanderkooy, John. An Electrostatic Experiment of Lord Kelvin with Running Water. Phys 13 news, DP, U of Waterloo, Ontario. January, 1984.
- [2] Zahn, Markus. Self-Excited ac High Voltage Generation Using Water Droplets. AJP. Vol 41. pp 196~202. 16, August, 1972.