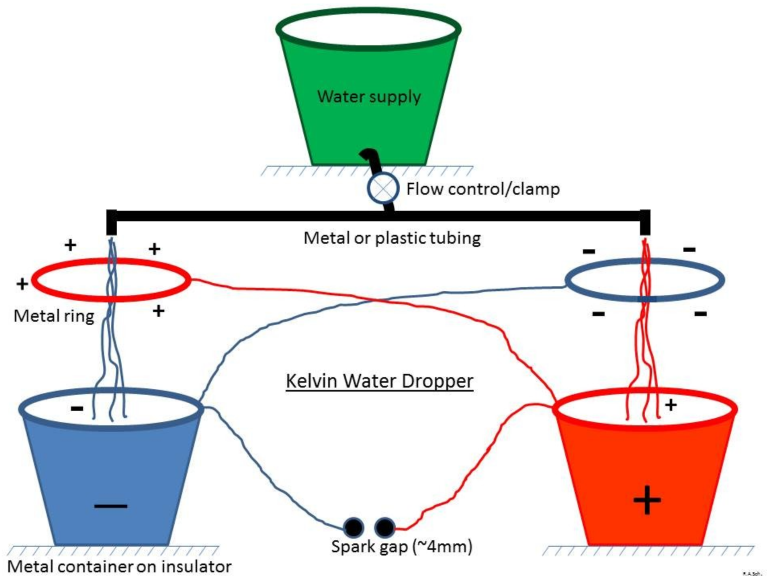
Kelvin water dropper

The **Kelvin water dropper**, invented by British scientist William Thomson (Lord Kelvin) in 1867, is a type of electrostatic generator. Kelvin referred to the device as his **water-dropping condenser**. The apparatus is variously called the **Kelvin hydroelectric generator**, the **Kelvin electrostatic generator**, or **Lord Kelvin's thunderstorm**. The device uses falling water to generate voltage differences by electrostatic induction occurring between interconnected, oppositely charged systems. Its only use has been in physics education to demonstrate the principles of electrostatics.

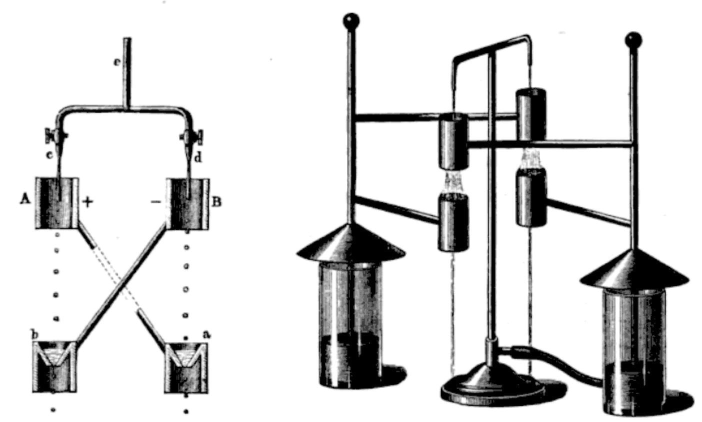


Typical setup for the Kelvin Water Dropper.

Description

A typical setup is as pictured. A reservoir of conducting liquid (water or otherwise) has holes or piping that releases two falling streams. Each stream passes without touching through a conducting ring, and lands in one of two containers. The containers must be electrically insulated from each other and from electrical ground. Similarly, the rings must be electrically isolated from each other and their environment. The left ring is electrically connected with (wired to) the right container and the right ring is wired to the left container. It is necessary for the streams to break into separate droplets before reaching the containers. Typically, the containers are conductors, such as metal buckets.

Principles of operation



This drawing appears in many early textbooks, and may be the original form of the apparatus. Instead of buckets, after falling through the charging electrodes the drops fall into metal funnels which collect the charge but let the water through. This machine is equipped with Leyden jar capacitors *(cylindrical objects at base)* which store the charge

Any small charge on either of the two buckets suffices to begin the charging process. Suppose, therefore, that the right bucket has a small positive charge. Now the left ring also has some positive charge since it is connected to the bucket. The charge on the left ring will attract negative charges in the water (ions) into the left-hand stream by (Coulombic) electrostatic attraction. When a drop breaks off the end of the left-hand stream, the drop carries negative charge with it. When the negatively charged water drop falls into its bucket (the left one), it gives that bucket and the attached ring (the right one) a negative charge.

Once the right ring has a negative charge, it attracts positive charge into the right-hand stream. When drops break off the end of that stream, they carry positive charge to the positively charged bucket, making that bucket even more positively charged.

So positive charges are attracted to the right-hand stream by the ring, and positive charge drips into the positively charged right bucket. Negative charges are attracted to the left-hand stream and negative charge drips into the negatively charged left bucket. The positive feedback of this process makes each bucket and ring increasingly charged. The higher the charge, the more effective this process of electrostatic induction is. During the induction process, there is an electrical current that flows in the form of positive or negative ions in the water of the supply lines. This is separate from the bulk flow of water that falls through the rings and breaks into droplets on the way to the containers. For example, as water approaches the negatively-charged ring on the right, any free electrons in the water can easily flee toward the left, against the flow of water.

Eventually, when both buckets have become highly charged, several different effects may be seen. An electric spark may briefly arc between the two buckets or rings, decreasing the charge on each bucket. If there is a steady stream of water through the rings, and if the streams are not perfectly centered in the rings, one can observe the deflection of the streams prior to each spark due to the electrostatic attraction via Coulomb's law of opposite charges. As charging increases, a smooth and steady stream may fan out due to self-repulsion of the net charges in the stream. If the water flow is set such that it breaks into droplets in the vicinity of the rings, the drops may be attracted to the rings enough to touch the rings and deposit their charge on the oppositely charged rings, which decreases the charge on that side of the system. In that case also, the buckets will start to electrostatically repel the droplets falling towards them, and may fling the droplets away from the buckets. Each of these effects will limit the voltage that can be reached by the device. The voltages reached by this device can be in the range of kilovolts, but the amounts of charge are small, so there is no more danger to persons than that of static electrical discharges produced by shuffling feet on a carpet, for example.

The charge separation and build-up of electrical energy ultimately comes from the gravitational potential energy released when the water falls. The charged falling water does electrical work against the like-charged containers, converting gravitational potential energy into electrical potential energy, plus motional kinetic energy. The kinetic energy is wasted as heat when the water drops land in the buckets, so when considered as an electric power generator the Kelvin machine is very inefficient. However, the principle of operation is the same as with other forms of hydroelectric power. As always, energy is conserved.

Some details

If the buckets are metal conductors, then the built-up charge resides on the outside of the metal, not in the water. This is part of the electrical induction process, and is an example of the related "Faraday's ice bucket." Also, the idea of bringing small amounts of charge into the center of a large metal object with a large net charge, as happens in Kelvin's water dropper, relies on the same physics as in the operation of a van de Graaff generator.

The discussion above is in terms of charged droplets falling. The inductive charging effects occur while the water stream is continuous. This is because the flow and separation of charge occurs already when the streams of water approach the rings, so that when the water passes through the rings there is already net charge on the water. When drops form, some net charge is trapped on each drop as gravity pulls it toward the like-charged container.

When the containers are metal, the wires may be attached to the metal. Otherwise, the container-end of each wire must dip into the water. In the latter case the charge resides on the surface of the water, not the outside of the containers.

The apparatus can be extended to more than two streams of droplets. [1]

In 2013, a combined group from the University of Twente (the Netherlands) constructed a microfluidic version of the Kelvin water dropper, which yields electrical voltages able to charge, deform and break water droplets of micrometric size by just using pneumatic force instead of gravity. [2]

References

[1] Markus Zahn, "Self-excited a.c. high voltage generation using water droplets," *American Journal of Physics*, vol. 41, pages 196-202 (1973). (http://dx.doi.org/10.1119/1.1987174)
[2] Alvaro G. Marin et al.,"The microfluidic Kelvin water dropper". *Lab on a chip* (DOI: 10.1039/C3LC50832C). (http://arxiv.org/abs/1309.2866).

External links

- Video demonstrating Kelvin water dropper in operation: " 10, M.I.T. 8.02 Electricity & Magnetism, Spring [term] 2002 (http://youtube.com/watch?v=RQX8I9ZWtPQ&feature=relatedLecture)". See the last 6 minutes of this video for operation of Kelvin water dropper. Printed material related to this video: See "MIT Open Courseware" website; specifically, assignment 4 of course 8.02, which is available here: http://ocw.mit.edu/OcwWeb/Physics/8-02Electricity-and-MagnetismSpring2002/DownloadthisCourse/index.htm .
- Youtube - Kelvin Water Dropper: Implementation and Explanation (http://www.youtube.com/watch?v=8Jx1pvFiaoI)
- Youtube - Kelvin Water Dropper and How it Works (http://www.youtube.com/watch?v=sArNxGnYhNU)
- Detailed description of device and how to build your own Kelvin water dropper. (http://amasci.com/emotor/kelvin.html)
- Lego Kelvin water dropper (http://www.splung.com/content/sid/3/page/lego_kelvin_water_dropper)

Article Sources and Contributors

Kelvin water dropper *Source*: http://en.wikipedia.org/w/index.php?oldid=584940831 *Contributors*: 05kelvinwaters, Aamackie, Acdx, Acharya973, Alvarogum, AnthonyMartin, AySz88, Bgwhite, Cadmium, CharlesHBennett, Chetvorno, Cwkmail, Denisarona, Dispenser, Dustybunny, Edison, Euyyn, FayssalF, Forzan, Fuhghettaboutit, Gaianauta, GeeJo, Giftlite, Graeme Bartlett, H2earth, Halberdo, Heron, Jackfork, Jaeger5432, Ju66l3r, Karol Langner, KathrynLybarger, Kkmurray, Mais oui!, NorViking, PeterBFZ, Qwerty123uiop, Reddi, Sholto Maud, Sphks, Spike Wilbury, Supastremph, Svofski, Tsirel, Voidxor, Yangfl, 41 anonymous edits

Image Sources, Licenses and Contributors

File:Kelvin_Water_Dropper_jpeg_version.jpg *Source*: http://en.wikipedia.org/w/index.php?title=File:Kelvin_Water_Dropper_jpeg_version.jpg *License*: GNU Free Documentation License *Contributors*: Qwerty123uiop

Image:Kelvin water-dropper electrostatic generator.png *Source*: http://en.wikipedia.org/w/index.php?title=File:Kelvin_water-dropper_electrostatic_generator.png *License*: Public Domain *Contributors*: Chetvorno

License

Creative Commons Attribution-Share Alike 3.0
//creativecommons.org/licenses/by-sa/3.0/