In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

The Inveterate Tinkerer
1. Salt Oscillator

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In this series of articles, the authors discuss various phenomena in fluid dynamics, which may be investigated via tabletop experiments using low-cost or home-made instruments. The first article in this series is about the salt oscillator – a hydrodynamic curiosity.

Materials Required

Syringe (15 ml), glass beaker (500 ml), micropipette tip, sodium chloride (NaCl), deionized water, data-acquisition card, copper wire, methylene blue, crocodile clips, copper strips.

Method

Prepare a 50 ml solution of sodium chloride using deionized water by mixing 11.7 g (4M) in 50 ml of water. An overhead/magnetic stirrer may be used for mixing. Add ∼ 10 drops of methylene blue to improve the contrast. Fill about 350 ml of deionized water in the beaker.

Use a surgical blade to cut the end of the micropipette tip to enlarge the opening (to a diameter ∼ 1mm) and force-fit the micropipette tip to the syringe. Set up a 'bridge' for supporting the

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Oscillator, fluid dynamics.

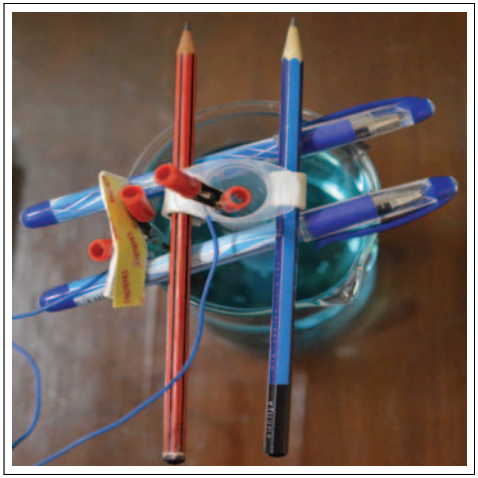

Figure 1. Top-view of the setup.

The downward and upward moving jets alternate periodically, and the oscillations continue until the liquids inside and outside the syringe equalize in density.

syringe. We used two pens, two pencils and some double-sided tape (see *Figure* 1). Fill up the syringe with NaCl solution (5 ml is sufficient) keeping your finger at the tapered end of the micropipette tip, and place the syringe on the bridge (see *Figure* 2). As soon as you release your finger from the open end of the micropipette tip, the salt solution streams downwards as a turbulent jet. After a few minutes, the level of the water in the beaker is higher than the level of the salt solution in the syringe, due to the higher density of the salt solution. The flow rate of the jet diminishes until the flow stops. You can now see a jet of water penetrating the tip and moving upwards into the syringe. The flow upwards eventually diminishes and stops. Subsequently, a jet of (diluted) NaCl solution streams downwards with the formation of a vortex ring. The downward and upward moving jets alternate periodically, and the oscillations continue until the liquids inside and outside the syringe equalize in density.

Non-sinusoidal oscillating voltage signal synchronizes with the upward and downward motion of the jets.

Use a data-acquisition card (DAQ) for recording the voltage difference. Crocodile clips are used to connect the copper wire with the copper strips. The copper strip inserted in the syringe acts as one electrode, and the copper strip which is inserted into the water in the beaker acts as the reference electrode. We used a National Instruments USB-6211 DAQ card for our measurements. Note the non-sinusoidal oscillating voltage signal, which synchronizes

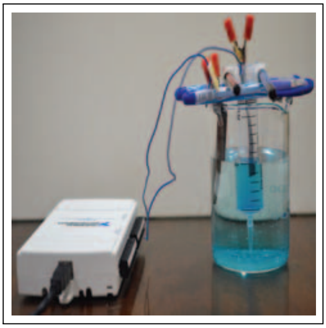

Figure 2. Side-view of the setup.

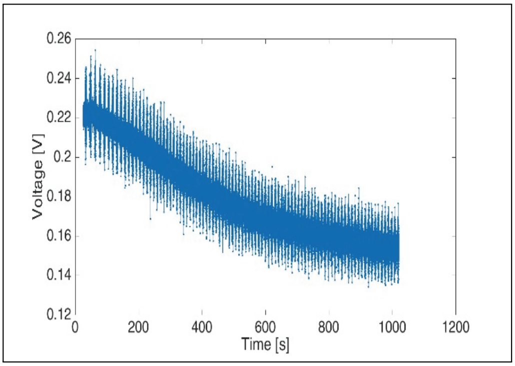

Figure 3. Voltage vs. time for the salt oscillator (4M NaCl).

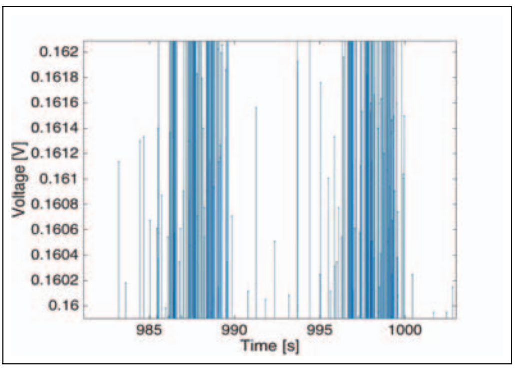

Figure 4. Voltage vs. time for the salt oscillator (close-up view).

with the upward and downward motion of the jets (see *Figure* 3, and close-up view in *Figure* 4). Avoid disturbing the setup once the oscillations set in.

The classic Rayleigh–Taylor problem [1] concerns the instability of the interface between a dense liquid, overlaying a less dense liquid. The interface between the two liquids is unstable to large-wavelength perturbations. The interface is never perfectly ‘flat’, and an intentional or spontaneous disturbance destabilises the interface. A fluid element in the less dense fluid penetrates into the upper (denser) fluid and accelerates upwards due to buoyancy. Similarly, a fluid element of higher density which penetrates into the lower liquid accelerates downwards due to gravity. Some papers that describe this phenomenon [2–4] suggest that the oscillations are a consequence of transitions between two steady states *viz.* with the micropipette tip filled with salt solution and with the micropipette tip filled with deionized water.

A close-up view of the jet may be seen in the following video: youtube.com/watch?v=VUfnKIycOYg

Scan the QR code to view the video.

Suggestions for Further Work

1. What happens to the oscillation period if you mix a half-teaspoon of surfactant (soap solution) to the water in the beaker?

2. What happens to the oscillation period if you increase the dynamic viscosity of the water in the beaker, by adding corn syrup/glycerol?

3. Add a pinch of polymer such as polyethylene oxide/polyacrylamide to the salt solution, and stir thoroughly using a magnetic stirrer. What happens to the oscillation period? Is there any visible change in the structure of the jets?

4. Change the outlet diameter of the micropipette tip by successively cutting the end of the tip to enlarge the diameter. Repeat the experiment and observe any changes in the oscillation period. Is there a range of tip diameters over which the oscillations are observed?

5. Reduce the concentration of the salt solution in discrete steps and observe any changes in the oscillation period.

6. Try the experiment using a mixture of 50% aqueous glycerol mixture in the syringe and deionized water in the beaker outside.

Both liquids have very low conductivity. Do you observe an oscillating voltage signal? What happens if you add a few drops of methylene blue to the mixture in the syringe?

7. Repeat the experiment with two identical syringes instead of one. You now have a system of two coupled oscillators [5]. Do the voltage signals from the two oscillators show any phase- or frequency-locking after transients die down?

Acknowledgement

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Suggested Reading

[1] Jearl Walker, Amateur Scientist: The Salt Fountain and Other Curiosities Based on the Different Density of Fluids, *Scientific American*, October, p.142, 1977.

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