Demonstrating atmospheric electrification phenomena

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1. Abstract
Lightning is both widely experienced and commonly recognised as electrical in origin. Studying atmospheric electrical effects in the classroom, however, generally requires high voltage sources and in some cases may not be possible. Generating high voltages through electrostatics can provide good and controllable laboratory demonstrations, through which phenomena related to lightning discharges can be experienced and explained. This adds an experiential element to education in atmospheric electricity that can be explained at a variety of technical levels, from school children to the general public to final year undergraduate students.

2. Introduction
Thunderstorm electricity is one of the oldest experimentally investigated topics in atmospheric science, dating to about 1752 with the ideas of Benjamin Franklin. The experimental concepts were widely imitated, and ultimately served to establish that the electricity present naturally in thunderclouds was the same as the electricity that could be made by machines in laboratories (Aplin et al, 2008).

Electrostatics became a highly fashionable topic in the 1800s. Its success was partly due to the use of demonstrations, in which sparks and shocks were generated for audiences to witness and, in some cases, feel. The significance of the primal force of electricity should not be underestimated. It has underpinned successful literature such as Mary Shelley's *Frankenstein*, and major international science museums stage electrostatics shows in their galleries, This experiential aspect of electrostatics is therefore still able to draw crowds and pique curiosity.

We build on this for modern laboratory demonstrations of atmospheric electrical phenomena and instrumentation. This poster describes demonstrations used in the atmospheric electricity course at Reading University for 3rd and 4th year undergraduates in Meteorology, and at Oxford University to advertise the Physics Teaching Labs at Open Days for prospective students.

3. Wimshurst Machine
The breakdown field strength of air is a key property in the generation of lightning. When an electric field exceeds the breakdown field, air no longer functions as an insulator and a current flows. A demonstration can be used with students to show this effect, but substantial voltages are required. These can be produced by an electrostatic generator demonstration, such as a Wimshurst machine, shown in Figure 2. Students are asked to estimate the breakdown strength of air, and then a variety of electrode separations used to establish a numerical result.

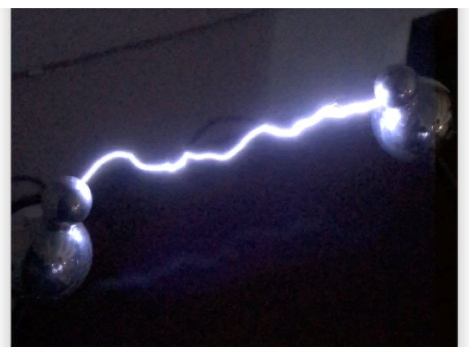

Fig 1 Typical discharge from the Wimshurst machine across a spark gap of 10 cm.

Video of Wimshurst machine in action

Fig 2 (left) A Wimshurst machine. Disks with multiple coupon electrodes counter-rotate, and generate a substantial charge by friction (middle) View of the electrodes, the spacing between which can be varied to find the breakdown distance at different potential differences (right) For safety, the potential difference across the electrodes is measured with an optically isolated voltmeter. The measurements are sent optically to a readout, on the student side of the bench.

4. Kelvin water dropper generator
Two additional important concepts in atmospheric electricity are that droplets can carry charge, and that drops can be polarized in an electric field. The water dropper *generator* exploits the polarization of water drops to generate a high enough voltage for sparks to be seen. It was developed by Lord Kelvin (Thomson, 1867), based on technology he invented for measuring the atmospheric electric field with water drops (Aplin and Harrison, 2013), known as the water dropper *equalizer*.

The Kelvin water dropper generator involves two streams of water dripping through a pair of ring electrodes into a conducting vessel, with opposing rings and vessels connected, figure 3. It can be constructed simply, and used to generate sufficiently high voltages to cause small sparks with just water and gravity. This provides a basis for explaining inductive charging and the polarisation of water droplets, and a source of detectable radio frequency energy from the electrical discharge.

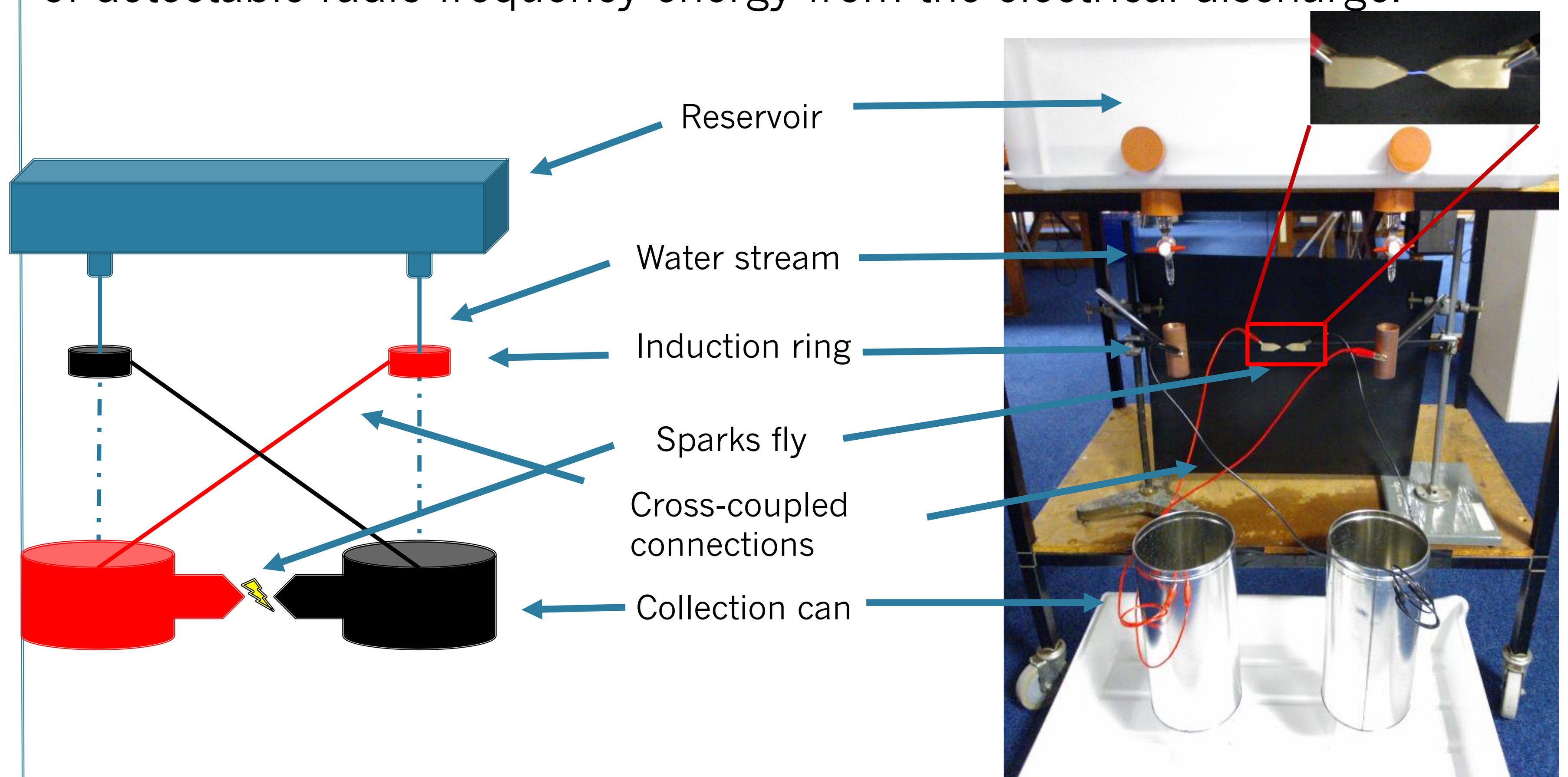

Fig 3 Kelvin water dropper generator (left) conceptual diagram (right) photograph of apparatus set up for an open day, with zoomed inset to the spark

Video of Kelvin dropper generator in action

5. Lightning location
During the late nineteenth and early twentieth centuries, it was realised that the large and fluctuating electrical currents associated with lightning were responsible for brief but broad-band radio signals known as *sferics* (a contraction of the word 'atmospherics'). These can be heard as brief clicks and pops on an AM radio during a storm. Scientists in the UK exploited this characteristic to locate lightning. As their knowledge grew, their apparatus became more sophisticated, eventually forming the modern ATD (Arrival Time Difference) lightning detection system now run by the UK Met Office. The basic principles are simple however. Any electrical discharge, such as that from the Kelvin water dropper generator, produces a radio pulse which can be used to detect the location of thunderstorms.

The discharges generated in the demonstrations shown here can be used, or, even more simply, a piezoelectric lighter intended for gas stoves. At Reading, students triangulate the position of the "lightning" with a simple radio receiver, an all-weather exercise (Fig 4)

Fig 4 Students locating simulated lightning with a simple receiver

6. Conclusions
Simple demonstrations, often with readily constructed equipment, can be used to safely illustrate many concepts in atmospheric electricity. These are suitable for many different contexts and learning stages.

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