The Millikan Experiment

**Background Theory and Apparatus**

The aim of this experiment is to determine whether electric charge is quantised and to investigate the size of the elementary charge.

You will study the movement of oil droplets in an electric field as shown in Figure 1. The oil spray produces a mist of oil droplets in the upper chamber. These droplets fall through the small opening to the lower chamber where they are ionised by alpha radiation, causing the droplets to gain either a positive or negative charge. The lower chamber has a uniform vertical electric field where the movement of droplets can be viewed under a microscope on a computer monitor connected to the camera.

When the electric field in the lower chamber is zero all the droplets will fall downwards (Figure 2). This is because the only two forces acting on the droplets are the weight $mg$ and the drag force $kv_f$, which depends on the velocity ($v_f$). In this case droplets reach a downwards terminal velocity when the drag force balances with the weight, so $mg = kv_f$.

However, when there is a non-zero electric field a droplet experiences an additional electric force, $Eq$, whose direction depends on the magnitude and sign of the charge, $q$, and the magnitude and direction of the electric field, $E$. The situation depicted in Figure 3 shows a droplet moving with upwards terminal velocity due to an upwards electric force which balances with the weight and the drag force, so that $Eq = mg + kv_f$.

The experimental procedure allows a determination of the magnitude of the elementary charge as follows. As droplets are sprayed into the chamber they are irradiated. Following this ionisation a single droplet is selected and its downwards ($E = 0$) and upwards ($E \neq 0$) motion recorded. When the droplets are irradiated again the electric charge on the droplet will (hopefully) change, and the new motion can be recorded. This measurement of motion for different ionisations is repeated for the same droplet many times. Millikan’s original results showed that the electric force acting on the droplet can only take certain values related to each other by small integers, thus indicating that electric charge is quantised. When the density of the oil droplet is known, the smallest change in this quantised charge can be determined. This analysis requires use of Stokes’s Law describing the motion of spherical objects in a medium and accurate results should take into account buoyancy as well as the temperature and pressure in the chamber, since these factors affect the density of air and thus the drag force or viscosity.
**The qualitative experiment**

The qualitative experiment is not intended to determine the magnitude of the elementary charge, only to detect that a droplet has quantised values of charge. When droplets are observed in the presence of both the electric field and the ionising radiation you should notice that droplets will occasionally change their direction of motion or accelerate.

• Familiarise yourself with the equipment and identify the components labelled in the diagram. The camera, which is directed through the microscope, is omitted from the diagram. This camera is connected to the computer, which only displays the images from this camera.
  • The important controls are
    - the *electric field switch* which selects the direction of the field or switches the field off
    - the *ionisation control*, which turns the ionising radiation on and off (ON - OFF) as well as opening the air valve to allow the droplets to enter the chamber (Spray Droplet Position)

![Diagram of equipment](image)

• If necessary, adjust the camera and its zoom so that the measurement coordinate system on the monitor is evenly lit. The camera is attached to the microscope eyepiece rim.
• Turn the high-voltage source on and adjust the voltage to 500 V. Turn the electric field switch to *Grounded Plates*.
• Turn the ionisation control to *Spray Droplet Position*.
• Place a paper towel over the nozzle of the oil spray and pump the spray a few times until you hear the oil coming out.
• Place the nozzle of the oil spray in the chamber lid opening. Sharply squeeze the ball of the oil spray once; this will produce a mist of droplets in the upper chamber. Hold the nozzle over the opening and this time squeeze the ball slowly to allow an air stream to introduce droplets into the lower chamber. Keep the ball squeezed, lift the nozzle out of the slot and only then release the ball. The mist of oil droplets should now appear in the camera’s image on your monitor.
• Turn the ionisation control to *ON* and the electric-field switch to *Top Plate is Negative*.
• Observe the oil droplets falling downwards. Do you notice any droplets suddenly start to rise or experiencing acceleration? Why do you think this is?

• If necessary, you can spray more droplets into the chamber. To do this, turn the ionisation control to *Spray Droplet Position*. Insert the nozzle into the opening of the chamber and first slowly squeeze the ball. If the droplets do not appear, squeeze the ball first sharply and then slowly. When the droplets appear, turn the ionisation control to the *ON* position.
• If no droplets appear at all this may be because the small hole between the upper and lower chamber has become blocked. In this case ask your supervisor to clear the blockage.
**Determination of velocity of the droplets**

Here you will use a different computer. The programme LoggerPro will use pre-recorded video to analyse the upward and downward motion of an oil droplet. An example of a video in which a droplet changes speed is stored in the computer.

- To view the video, click: Insert - Movie: DROPLET EXAMPLE / ESIMERKKI TÄHÄN
- To set the origin to a new location, click on the *Set Origin* button, then click the position you want to set the origin. You can rotate the coordinate system using the yellow, circular icon; so that the horizontal axis is parallel to the measurement's horizontal axis.
- To set the scale, click *Set Scale* button, then using the mouse drag a line of known length on the video image (each small square of the coordinate system has a width of 0.1 mm).
- Find a part of the video where you want to start the analysis and click on the *Add Point* button.
- To track a droplet you should mark its location with the mouse. The image will remain marked and the video will progress frame by frame. Continue marking in this way until the motion of the droplet you are analysing has finished. Turn the *Add Point* option off by clicking the corresponding button.
- The program has now drawn graphs of the droplet motion in the X-and Y-direction. Click on the vertical axis title, and then choose the Y-coordinate.
- The speed of the oil droplet can be tracked at various points by clicking the mouse on the desired area of the graph and selecting Analyze - Linear Fit.