Lab in a Box – Millikan's oil drop experiment

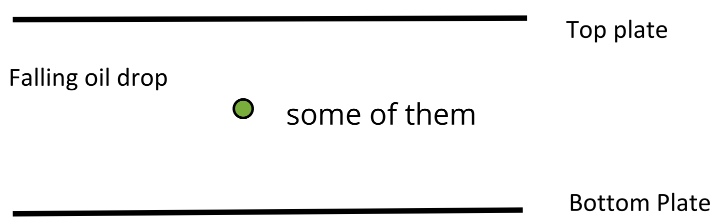
Safety Precautions

The mains voltage in the mains powered equipment is dangerous but is screened in normal use.

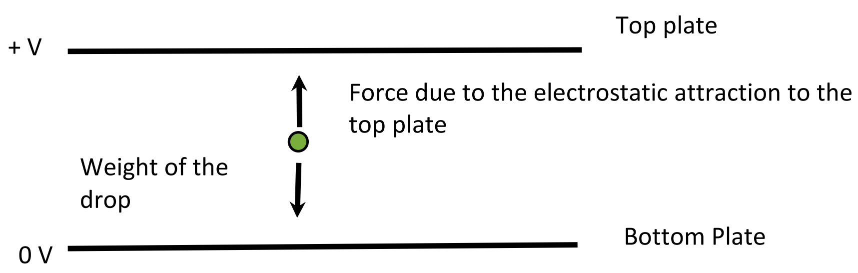
Introduction

At the start of the 20th century scientists knew about the existence of electrons and knew they had an electrical charge. Millikan's oil drop experiment was able to measure the charge oil drops. If it is assumed that all electrons have the same charge, then the charges on oil drops must be multiples of that charge. This experiment measures the charge on an oil drop.

Principles



When small oil drops are sprayed from a nozzle, some of them become electrically charged owing to frictional effects. In Millikan's experiment such oil drops are sprayed into a volume between two closely-spaced horizontal metal plates that are insulated from each other.



The drops can be kept from falling by applying a Voltage across these plates.

Developing an equation to find the charge on the drop q:

The upward force on the drop from the voltage on the plates = $(V / d) \times q$

where q is the charge on the drop

d is the spacing between the plates

V is the voltage across the plates

The downward force on the drop = weight = mg

A spherical drop has a radius r so the volume = $4/3\,(\pi r^3)$

Lab in a Box – Millikan’s oil drop experiment

If Density = mass / volume then

Mass = density X volume = $(4/3)\pi\rho r^3$ where ρ is the density of the oil,

The downward gravitational force on the drop = mg

= $(4/3)\,\pi g\rho r^3$

The drop is in air, not a vacuum, so there must also be an upward buoyancy force owing to the volume of air displaced,

The upthrust (due to the buoyancy) = $(4/3)\,\pi\rho_a g r^3$, where ρ_a is the density of air.

With some maths we can put these equations together to give:

$$q = (4/3)\,\pi(\rho - \rho a)g\, r^3\, d / V$$

Now all these quantities could be measured to determine *q*.

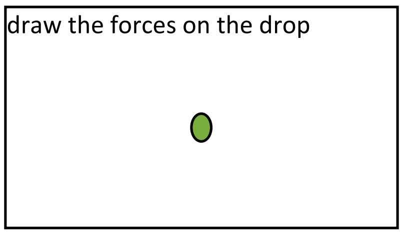
However, it is difficult to measure r directly because it is so small. Millikan realised that r could be measured by turning off the voltage and letting the drop fall.

As the drop falls down through the viscous air, it experiences an upward drag force given by Stokes’s law,

Upwards drag force = $6\,\pi\eta r v$

where η is the viscosity of air and

v is the speed of the drop.



When the upward buoyant and viscous forces balance the downward gravitational force, then the drop no longer accelerates, and moves at its *terminal velocity*, v_t.

Draw a sketch of the balance of forces,

It can be shown that

$$r = 9\sqrt{[\eta\, v_t / 2\,(\rho - \rho a)g\,]}$$

.The drops reach terminal velocity very quickly, and this can be measured by timing how long it takes a droplet to fall a measured distance. Thus we can substitute for r and gain an expression for q that contains quantities that can all be measured,

Lab in a Box – Millikan's oil drop experiment

$$q = (9\pi\, d / V) \sqrt{\ [2\, \eta^3 v_t^3 / (\rho - \rho_a) g]}$$

Experiment

Use the desk lamp angled towards the oil drop chamber to give an even and bright illumination on the TV screen, and make sure that you can read the graticule scale. If not, ask a demonstrator.

Make sure that the oil exit pipe is in line with the small holes on the chamber and give one or two sharp squirts of the bulb to spray oil into the gap between the metal plates.

Use the control on the telescope to focus on the oil drops and wait for the sideways motion to cease. You may need to place an object next to the small holes to minimise air currents.

Switch on the voltage supply to the metal plates, and watch the charged drops move up and down as you vary the potential difference.

Choose a bright, easy-to-see oil drop which is near to the graticule, and use the voltage control to move it down near the top of the screen. Hold it there by fine-tuning the voltage.

Record this value of V.

Next, turn off the voltage and start the stop clock.

Watch the drop as it falls.

You will need to keep focussing as it drifts downwards. It is best to let it fall as far as possible to

minimise the uncertainties in timing and distance.

Once it has fallen through 6 large graduations on the screen, stop the clock and record the time and distance it has fallen.

Note that the distance you measure has to be divided by 2 to take account of the magnification of the scope.

Use your measurements to calculate a value for q_c. Use the equation from above.

$$q = (9\pi\, d / V) \sqrt{\ [2\, \eta^3 v_t^3 / (\rho - \rho_a) g]}$$

Now repeat this 6 times (if possible), and use the Millikan spreadsheet (ask demonstrator) to obtain an average value for e, the electronic charge.

The values of the constants used in this experiment are:

Lab in a Box – Millikan's oil drop experiment

air viscosity, η = 1.83 ± 0.04 × 10^{-5} Nsm^{-2}

oil density, ρ = 874 ± 2 kgm^{-3} at 20 °C

air density, ρ = 1.30 ± 0.05 kgm^{-3} at 20 °C

plate spacing, d = 6.00 ± 0.05 × 10^{-3} m

friction coefficient, A = 7.7776 ± 0.0001 × 10^{-8} m

Attempt	Pd to keep drop the drop steady / V	Distance Drop falls 'up' /m	Time taken /s	Terminal velocity v_t / ms^{-1}

Which measurement gives the greatest uncertainty? Calculate the percentage error.

How does your result compare to the excepted value of 1.6 X 10^{-19} C

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Risk Assessment

Task: SUPI event – Laborator demonstrations of Millikan's experiment			
Department	Physics	Assessment ID	
Assessor	Phil Furneaux	Date of assessment	30-09-16
Authorised by		Review date	

Step 1 List significant hazards	**Step 2** who might be harmed	**Step 3** determine appropriate controls	**Step 4** make it happen
Electric shock The plates could be at a pd of 400V	Person setting up experiment	Ensure the power plug lead is off when any adjustments are being made Sing next to the experiment stating HIGH VOLTAGE	procedure
Damage to equipment		The apparatus will only be used under supervision of a demonstrator	supervision