BIRZEIT UNIVERSITY

Faculty of Science

Physics Department

Physics 212

The Millikan Oil Drop

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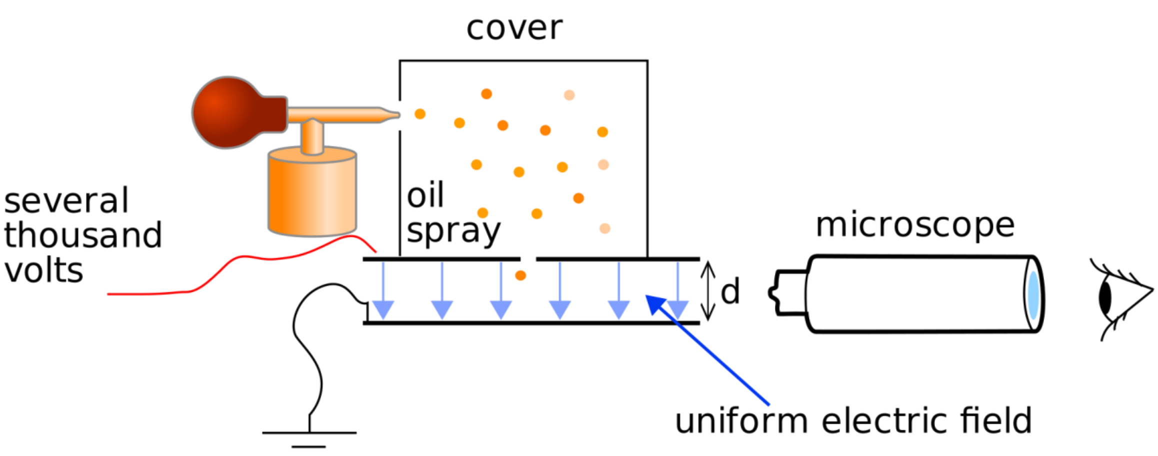
– Abstract:

The aim of this experiment is to determine the charge of a single electron and to demonstrate the quantization of charge. By measuring the charges of several oil droplets, the charge of electron was calculated. The charge of electron in this experiment was $1.71504 \times 10^{-19}\ C$.

– Theory:

In 1909, Robert Millikan conducted the oil drop experiment to determine the charge of an electron. He suspended tiny charged droplets of oil between two metal electrodes by balancing downward gravitational force with upward drag and electric forces. The density of the oil was known, so Millikan could determine the droplets' masses from their observed radii (since from the radii they could calculate the volume and thus, the mass). Using the known electric field and the values of gravity and mass, Millikan determined the charge on oil droplets in mechanical equilibrium. By repeating the experiment, he confirmed that the charges were all multiples of some fundamental value.



A potential difference V is applied across the plates. If the diameter of the plates is large compared to their separation d, then an approximately uniform electric field $E = V/d$ will be established between the plates. A droplet having charge q will experience a force $F = qE$. The potential difference V can be adjusted so that the electric force balances the gravitational force on the droplet. Then, the droplet will be suspended between the plates. If no net forces are acting on the droplet, it could move with a constant velocity.

$$\frac{qV}{d} = \frac{4}{3}\pi R^3(\rho - \sigma)g$$

where, ρ: density of the oil, σ: density of air, R: radius of the droplet, g: gravitational acceleration.

In order to find the charge q, the radius of the droplet R must be determined. This is done by measuring the free-fall velocity of the droplet and applying Stokes law. A sphere falling through a medium experiences a viscous drag (frictional force) equal to $6\pi nRv$, where v is the velocity of the sphere relative to the medium and n is the viscosity of the medium, which in this case is air. Since the frictional force is proportional to the velocity of the droplet, the droplet will eventually reach a constant velocity u, which we call, the terminal velocity. The terminal velocity is reached when frictional force balances the gravitational force.

$$\frac{4}{3}\pi R^3(\rho - \sigma)g = 6\pi nRu$$

$$R = \sqrt{\frac{9nu}{2(\rho - \sigma)g}}$$

$n = 18.1\ \mu Pa.s$, $\rho = 922\ kg/m^3$, $\sigma = 1.1839\ kg/m^3$, $g = 9.8\ m/s^2$

$$\frac{qV}{d} = 6\pi nRu$$

$$q = \frac{6\pi nRdu}{V}$$

The most recent value of electron charge is $1.60217662 \times 10^{-19}\ C$. Then,

$$multiple\ of\ e \approx q/1.60217662 \times 10^{-19}$$

The average value,

$$\bar{e} = \frac{\sum_{i=1}^{N} e_i}{N}$$

- **Procedure:**

Prepare the apparatus:

1. Focous the microscope until the droplets could be seen.
2. Turn on the potential difference to the maximum.
3. Add some oil droplets.
4. Change the potential difference until you could see a stopping droplet.
5. Record the value of the volts.
6. Turn off the potential difference and record the time which the droplet needed to pass 2.00mm.
7. Repeat the previous steps for 7 times.

– Data:

V(Volt)	Timer(sec)
353	19.82
386	12.38
351	21.64
416	20.00
502	10.25
495	16.52
419	11.76

$d = 2.00\ mm$

– Calculations:

V(Volt)	Timer(sec)	v(m/s)	R(m)	q(C)
353	19.82	0.000100908	9.54353E-07	1.86153E-19
386	12.38	0.000161551	1.20754E-06	3.44852E-19
351	21.64	0.0000924214	9.1334E-07	1.641E-19
416	20.00	0.000100000	9.50049E-07	1.55834E-19
502	10.25	0.000195122	1.32709E-06	3.51975E-19
495	16.52	0.000121065	1.04534E-06	1.74454E-19
419	11.76	0.000170068	1.23896E-06	3.43143E-19

q(C)	multiple of e	# multiple	e(C)
1.86153E-19	1.161877044	1	1.86153E-19
3.44852E-19	2.152395522	2	1.72426E-19
1.641E-19	1.024229666	1	1.641E-19
1.55834E-19	0.972639779	1	1.55834E-19
3.51975E-19	2.196852185	2	1.75987E-19
1.74454E-19	1.088855096	1	1.74454E-19
3.43143E-19	2.141733087	2	1.71572E-19

$\bar{e} = 1.71504 \times 10^{-19}\ C$

– Results:

$\bar{e} = 1.71504 \times 10^{-19}\ C$

– Discussion:

The value of charge of the electron in this experiment was $1.71504 \times 10^{-19}\ C$. Meanwhile, the value of it in more accuracy instruments is $1.60217662 \times 10^{-19}\ C$.

$$Error = \frac{|\bar{e} - e|}{e} \times 100\% = \frac{|1.71504 - 1.60218|}{1.60218} \times 100\% = 7.04417\%$$

The velocity of the droplets is constant for each droplet. Since, the drag force resists the increasing in the velocity, and then the droplets reach their terminal speed.

There are some sources of errors. For example, the systematic errors in the tools, like the source of potential difference, timer, and the scale in front of the microscope. Moreover, the accuracy in the values of oil density, air density, viscosity of the air, and the gravitational acceleration, make some errors in calculations.

– References:

1. H. Abusara, & A. Shawabkeh (2016, November). *Laboratory Manual: Modern Physics Lab* (Second Edition). *The Millikan oil drop* (pp. 37-48). Birzeit University: Faculty of Science.