Millikan Oil-Drop Experiment (Robert Millikan, 1909 - Harvey Fletcher 1913)

Determined value of e (1909-1913) - sqrt student

parallel plates in air

\[ F_d = \frac{qE}{2} \]

\[ mg \]

\[ \text{switch} \]

oil droplets

get negative charge q from ionization of air by x-rays in air (tungsten, changes effective q value)

\[ \Rightarrow \text{terminal velocity w/o} \ E \text{ from} \ F_d = 6\pi \eta r \frac{V}{r} = mg \]

\[ \Rightarrow V_{\text{off}} = \frac{-mg}{6\pi \eta r} (\uparrow E = 0) \quad (m = \rho \frac{4}{3} \pi r^3) \]

Add E to get upward terminal speed or balance

\[ 6\pi \eta r V = qE - mg \]

\[ \Rightarrow V_{\text{on}} = \frac{qE - mg}{6\pi \eta r} (\uparrow E \neq 0) = \frac{qE}{6\pi \eta r} + V_{\text{off}} \]

Turn E on and off, measure \( V_{\text{on}} - V_{\text{off}} = \frac{9E}{6\pi \eta r} \)

\( \text{of data} \quad \Rightarrow q = -ne, \quad n = 0, 1, 2, 3, 4, \ldots \)

(\text{Can also vary} \ E \text{ for more variety of data})

Millikan's main error from value of \( q \) what sort of material?
Capacitance - way of keeping track of charge and resulting potential.

Typically when charging an object (conductor) you move charge from one to another, equal and opposite charge.

Example:

\[ C = \frac{Q}{V} \]

Units: \( C = \text{Farad (F)} \)

1 F = huge capacitance (Because \( 1 \text{C} = \) huge charge)

You can calculate \( C \) for this example if you assume each metal ball has radius \( a \) and they're separated by \( d \).
Most common situation: parallel plates (may be wrapped up like a jelly roll)

\[ E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} \]  
(from HW earlier)

(If gap \( d \ll A \))

\[ V = Ed = \frac{Qd}{\varepsilon_0 A} \]

Makes sense: double the area, double the charge \( \sigma = \varepsilon_0 V/d \)

**ex.** Changed Sphere

Assume \( V = 0 \) at \( r = \infty \)

\[ C \text{ defined as } \frac{Q}{V(\infty)} \]

\[ V(\infty) = \frac{4\pi Q}{a} \quad \Rightarrow \quad C = \frac{Q}{V} = \frac{a}{k} = 4\pi\varepsilon_0 a \]

**ex.** Coaxial Cylinders (cable)

\[ \Delta V = V(a) - V(b) = \int Edr = \frac{Q}{2\pi L \varepsilon_0} \ln \left( \frac{b}{a} \right) \]

\[ C = \frac{Q}{\Delta V} = \frac{2\pi \varepsilon_0}{\ln(\frac{b}{a})} \]
Combining Capacitors

Symbols: \[ \text{T} \]

Parallel Capacitors

- \( Q_1 = V C_1 \) same voltage
- \( Q_2 = V C_2 \) on each "closed"
- positive plates connected

\[ C_{\text{eff}} = \frac{Q_1 + Q_2}{V} = C_1 V + C_2 V = C_1 + C_2 \]

Parallel Capacitors simply add

Series Capacitors

- \( Q = \frac{Q_1 + Q_2}{C_1 + C_2} \)

\[ \Rightarrow \frac{1}{C_{\text{eff}}} = \frac{1}{C_1} + \frac{1}{C_2} \]

Series capacitors add reciprocally