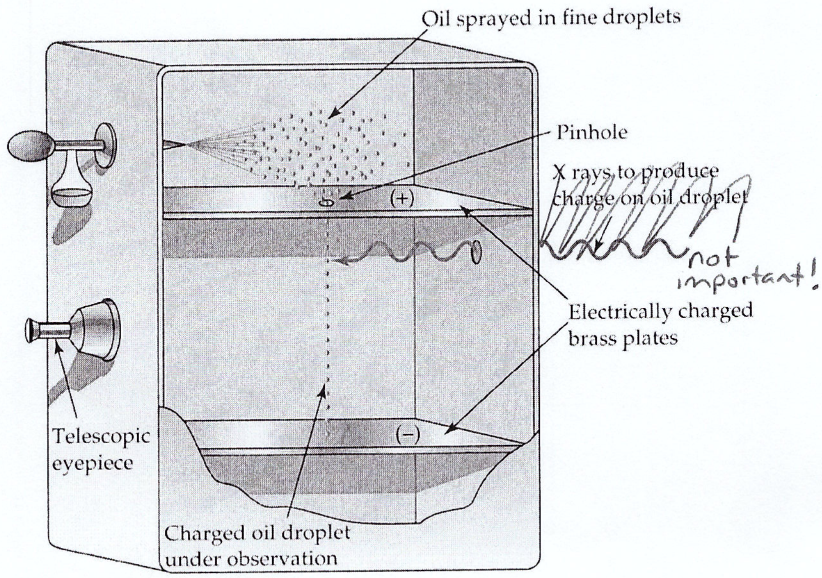
Millikan's Oil Drop Experiment

- Millikan performed an experiment from which he was able to determine the elementary charge of an electron
  - Recall, a negative charge is due to an excess of electrons and a positive charge is due to a shortage of electrons.

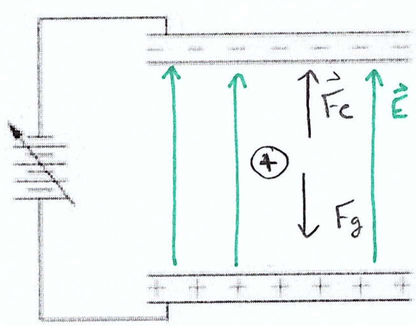
- In his experiment, he blew oil drops between horizontal parallel plates



- When no voltage was applied between the parallel plates, the oil drops would fall to the bottom plate due to the force of gravity (F_g). Force of gravity is now considerable because an oil drop is not an atomic particle and the mass of the oil drop is significant.

- When a voltage was supplied to the plates, some of the oil particles would rise to the top, some would remain suspended, and some particles would fall faster or slower to the bottom. All of these situations can be explained by the gravitational and electrical forces acting on the oil drop.

- When solving Millikan type problems, always start with a free body diagram and a F_{net} equation
  - When the oil drop (↳ oil drops) is suspended or moving at a constant speed (ie. no acceleration), the gravitational force and the electric force acting on the oil drop are equal (ie. F_{net} = 0.0N)



$$\vec{F}_{net} = \vec{F}_e + (-\vec{F}_g)$$

$$0 = \vec{F}_e - \vec{F}_g$$

$$\vec{F}_g = \vec{F}_e$$

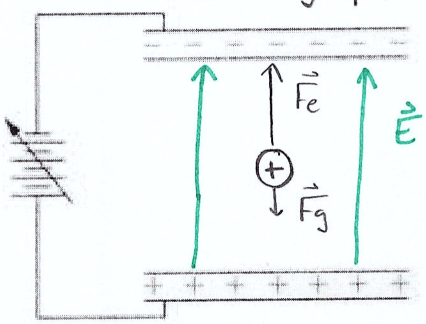
$$mg = \vec{E}q \quad \therefore \quad q = \frac{mg}{\vec{E}}$$

or

$$mg = \left(\frac{\Delta V}{d}\right)q \quad \therefore \quad q = \frac{mgd}{\Delta V}$$

- When the oil drop is accelerating (up or down), there is a F_{net} acting on the oil drop

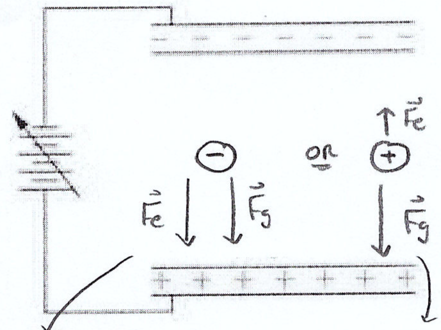
accelerating up.



$\vec{F}_{net} = \vec{F}_e + (-\vec{F}_g)$

$ma = \vec{E}q - mg$

accelerating down



$\vec{F}_{net} = \vec{F}_e + \vec{F}_g$

$ma = \vec{E}q + mg$

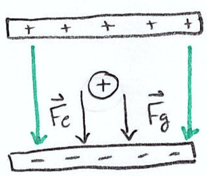
$\vec{F}_{net} = \vec{F}_g + (-\vec{F}_e)$

$ma = mg - \vec{E}q$

- Using this theory, Millikan was able to calculate the charge on thousands of different oil drops
- * In all of Millikan's trails, he found that the charges on all oil droplets were a *multiple* of 1.60×10^{-19} C. So he concluded that the charge on an elementary particle is 1.60×10^{-19} C.

EXAMPLES:

1. A 2.10×10^{-15} kg oil drop is placed in an electric field of 4.45×10^{5} N/C acting downwards. If the oil drop has a positive charge of 1.92×10^{-18} C. What is the acceleration experienced by the oil drop in the electric field?



$m = 2.10 \times 10^{-15}$ kg

$\vec{E} = 4.45 \times 10^{5}$ N/C

$q = 1.92 \times 10^{-18}$ C

$a = ?$

$\vec{F}_{net} = \vec{F}_e + \vec{F}_g$

$ma = \vec{E}q + mg$

$$a = \frac{\vec{E}q + mg}{m}$$

$$a = \frac{(4.45 \times 10^{5}\,N/C)(1.92 \times 10^{-18}\,C) + (2.10 \times 10^{-15}\,kg)(9.81\,m/s^2)}{(2.10 \times 10^{-15}\,kg)}$$

$$a = \frac{8.544 \times 10^{-13}\,N + 2.0601 \times 10^{-14}\,N}{2.10 \times 10^{-15}\,kg} = 416.6671\ldots\,m/s^2$$

$a = 417\,m/s^2$, down

$\vec{F}_{net} = 0 \therefore \vec{F}_g = \vec{F}_e$

2. An oil drop with a weight of $4.80\text{x}10^{-14}$ N is suspended between two horizontal parallel charged plates that are placed 5.00cm apart. If the potential difference between these plates is $3.00\text{x}10^{3}$V, how many excess electrons does the oil drop carry?

$\vec{F}_g = 4.80 \times 10^{-14} N$

$d = 5.00 cm \times \left(\frac{10^{-2} m}{1 cm}\right)$

$d = 0.0500 m$

$\Delta V = 3000 V$

$\#$ excess $e^- = ?$

↳ need total "q" first!

$\vec{E} = \frac{\vec{F}_e}{q}$ ②

$\vec{E} = \frac{\Delta V}{d}$ ①

① $\vec{E} = \frac{\Delta V}{d} = \frac{3000 V}{0.0500 m} = 6.00 \times 10^{4} V/m$

② $\vec{E} = \frac{\vec{F}_e}{q} \Rightarrow q = \frac{\vec{F}_e}{\vec{E}}$

$q = \frac{4.80 \times 10^{-14} N}{6.00 \times 10^{4} V/m} = 8.00 \times 10^{-19} C$

but $1e^-$ only has a charge of $1.6 \times 10^{-19} C$

$\therefore \# e^- = \frac{q_{total}}{q_{e^-}} = \frac{8.00 \times 10^{-19} C}{1.6 \times 10^{-19} C}$

$\boxed{\# e^- = 5}$

unit analysis

$\frac{N}{V/m} = \frac{N \cdot m}{V} \times \left(\frac{V}{(N/C) \cdot m}\right) = \frac{1}{1/C} = C$ ✓

$\vec{E} = \frac{\Delta V}{d}$

$(N/C) m = V$

Now try pg. 119 # 1c-f, 2, 3, 11 (acceptable), 5-8, 12, 15, 16 (intermediate), 13, 14 (excellence)

Use the following information to answer the next question.

In a modified Millikan apparatus, a small, charged object that has a mass of 3.8×10^{-15} kg is suspended by the electric field that is between charged parallel plates. The table below shows how the balancing voltage depends on the distance between the plates.

$\vec{F}_{net} = 0.0$ N

$\therefore \vec{F}_g = \vec{F}_e$

Plate separation (mm)	Balancing voltage (10^3V)
11.1	1.39
20.0	2.21
24.0	2.78
28.1	3.11
35.1	4.22

convert to m! $1\text{mm} = 10^{-3}$ m

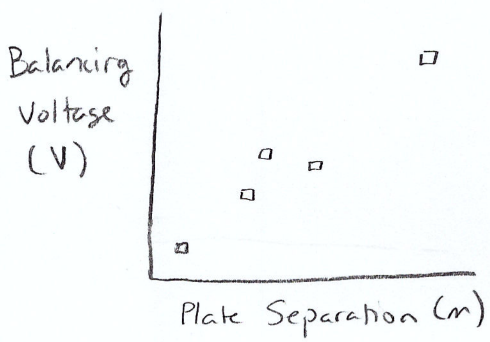
watch!

3.

a. Plot a graph of the data.

b. Use the slope of the graph to determine the magnitude of the charge on the suspended mass.

c. Determine the balancing voltage required when the plates are separated by 50.0mm.



window Settings

x: [0.0087, 0.0375, 2]

y: [908.9, 4701.1, 2]

$y = ax + b$

$a = 1.1646... \times 10^5$

$b = -13.4815...$

$\vec{F}_e = F_g$ b/c suspended

$\vec{E}q = mg$

$\left(\frac{\Delta V}{d}\right)q = mg$

$x = d$

$y = \Delta V$

$\therefore \Delta V = \frac{mgd}{q}$

$y = m\,x + b$

$\Delta V = \left(\frac{mg}{q}\right) d + 0$

$\text{slope} = \frac{mg}{q} \Rightarrow q = \frac{mg}{\text{slope}}$

$q = \frac{(3.8 \times 10^{-15}\text{kg})(9.81\text{m/s}^2)}{1.1646... \times 10^5} = 3.2009... \times 10^{-19}$ C

$q = 3.2 \times 10^{-19}$ C

******Now try pg. 122 # 9******

c.) $y = mx + b$

$y = (1.1646\ldots \times 10^5)x - 13.4815\ldots$

where $x = d$; $y = \Delta V$

$\therefore y = (1.1646\ldots \times 10^5)(0.0500\,m) - 13.4815$

$y = 5809.598\ldots$

$\boxed{\Delta V = 5.81 \times 10^3\ V}$