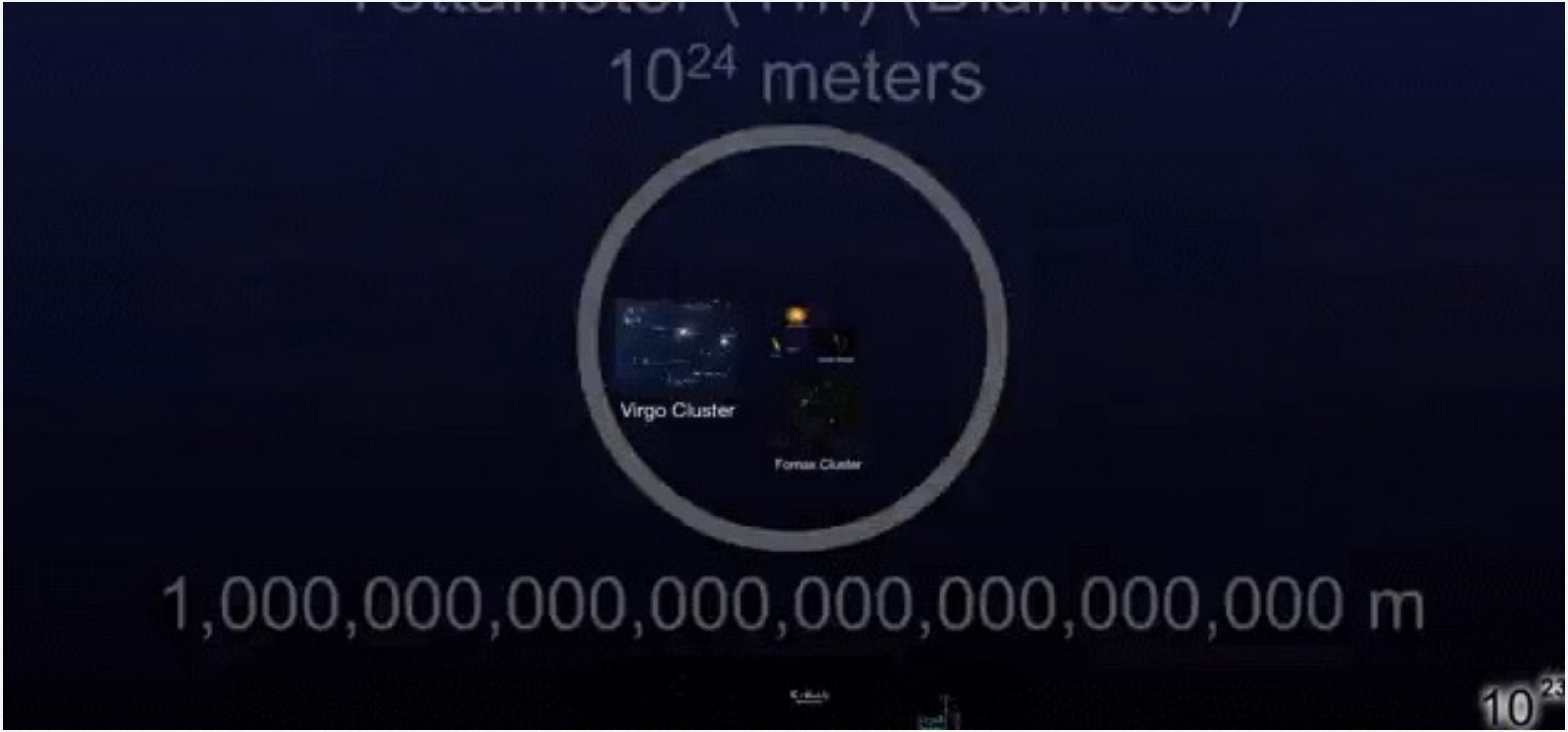
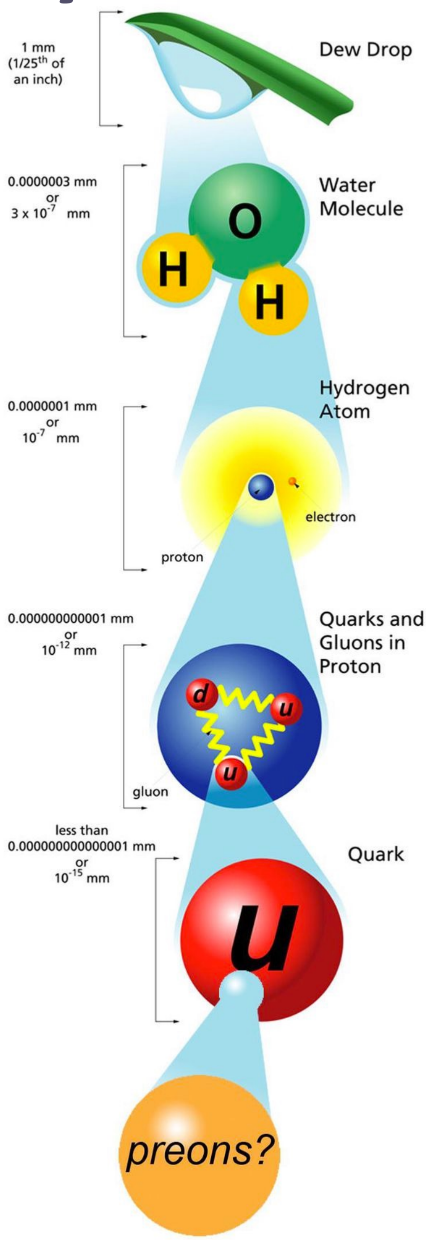
Millikan’s Oil-drop Experiment

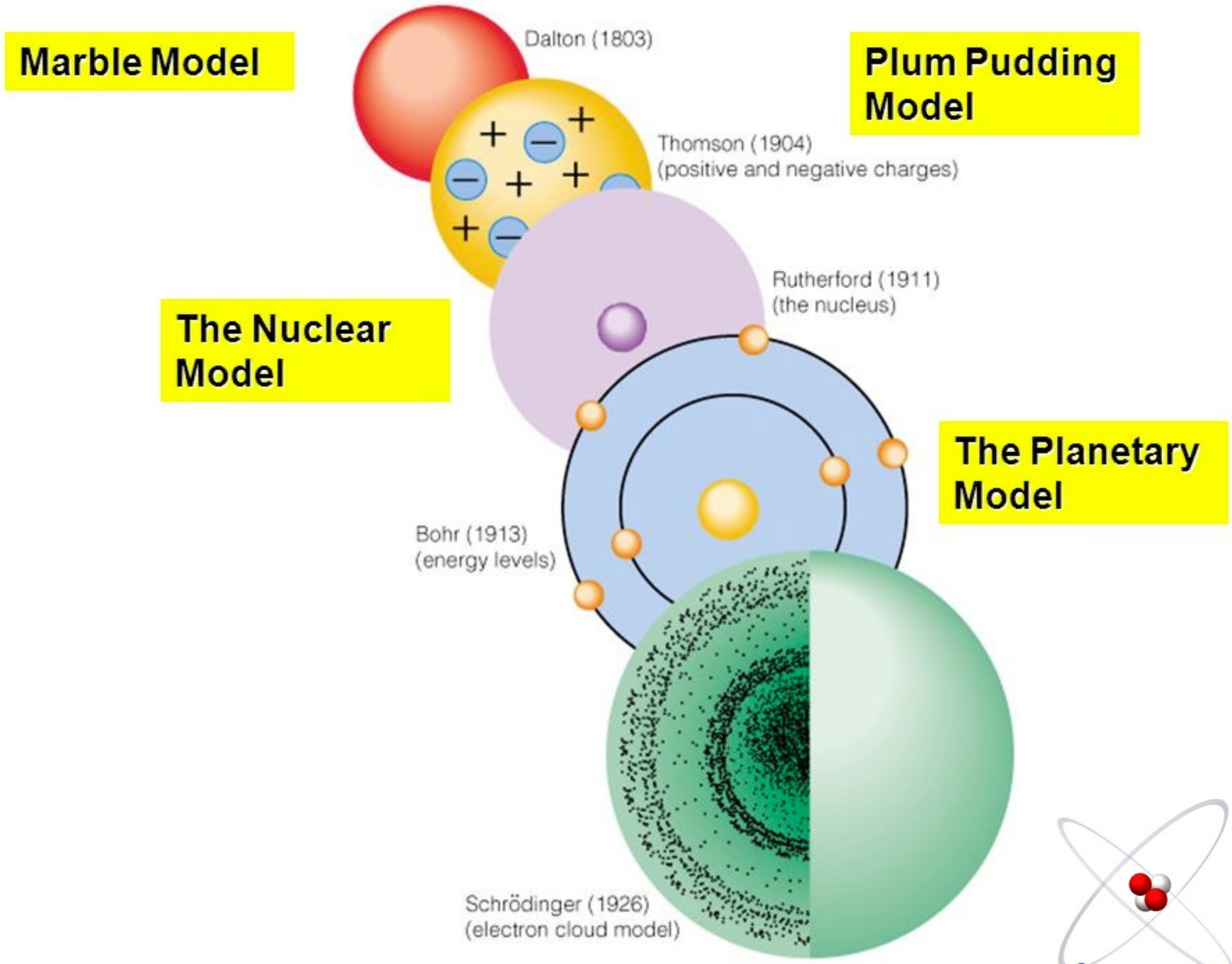
Mingquan He| College of physics

What is the smallest thing in universe?

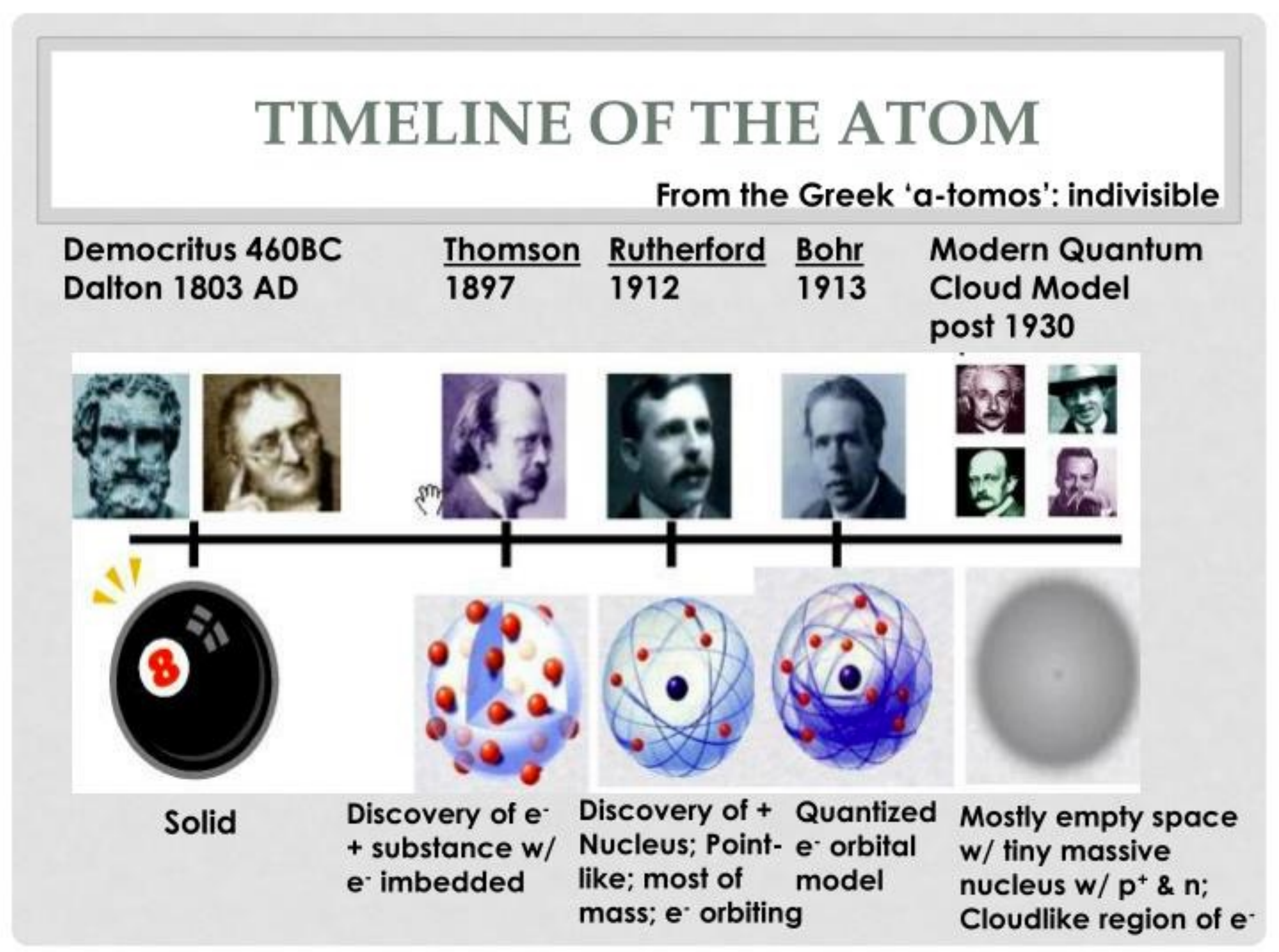


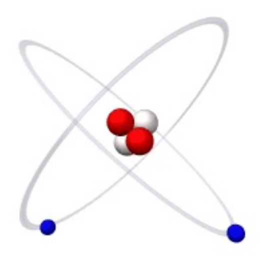
History of atomic model





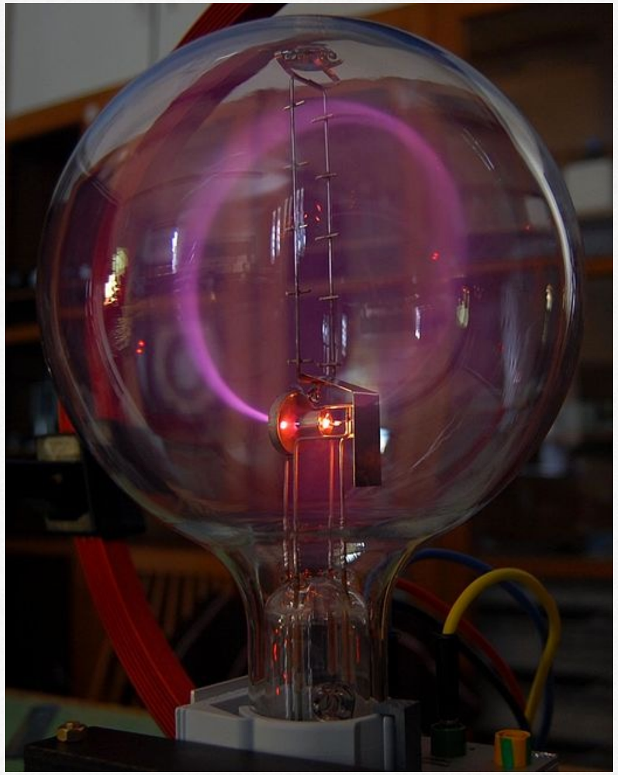
History of atomic model

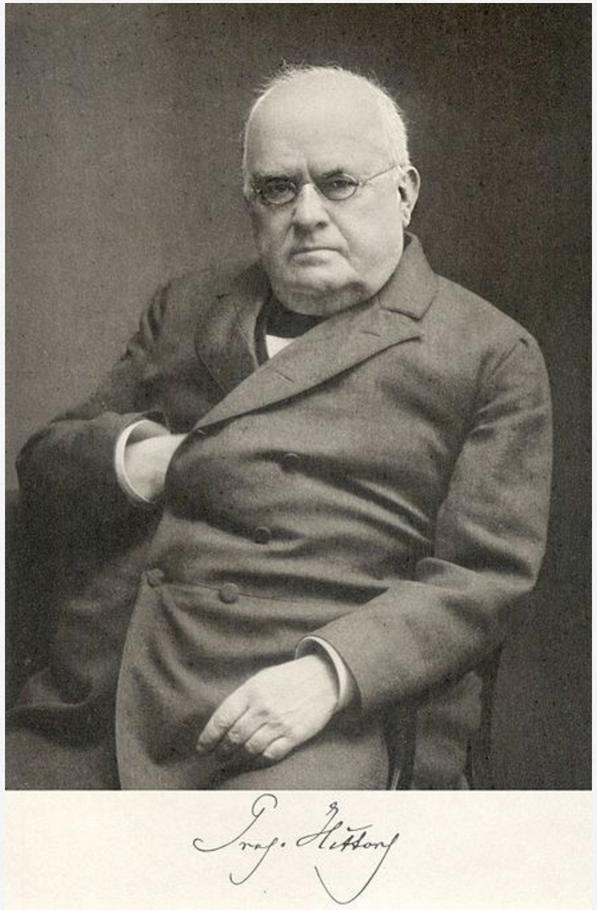




Electron

Cathode ray





1869 Discovered by J.W. Hittorf
1876 Named by E. Goldstein

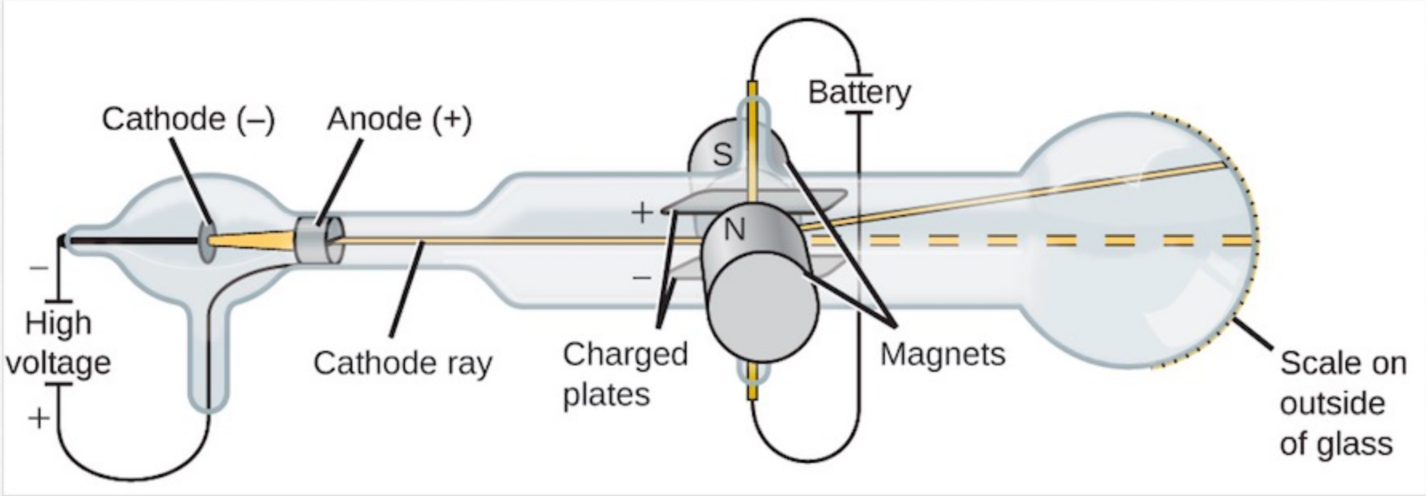
Johann Wilhelm Hittorf
(27.03.1824 – 28.11.1914)
German physicist

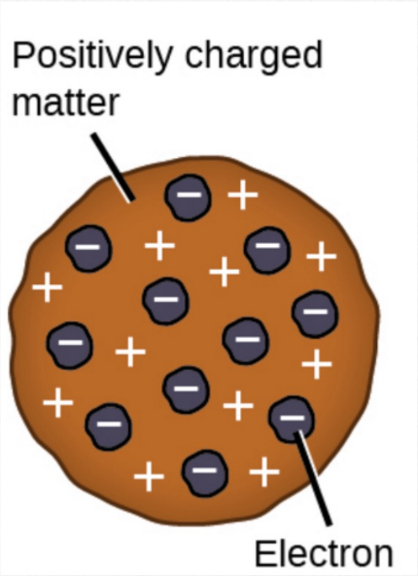
Eugen Goldstein
(5.9.1850 – 25.12.1930)
German physicist

Electron

Mass spectrometry

Sir Joseph John Thomson
(18.12.1856 – 30.8.1940)
English physicist
Nobel Prize in 1906





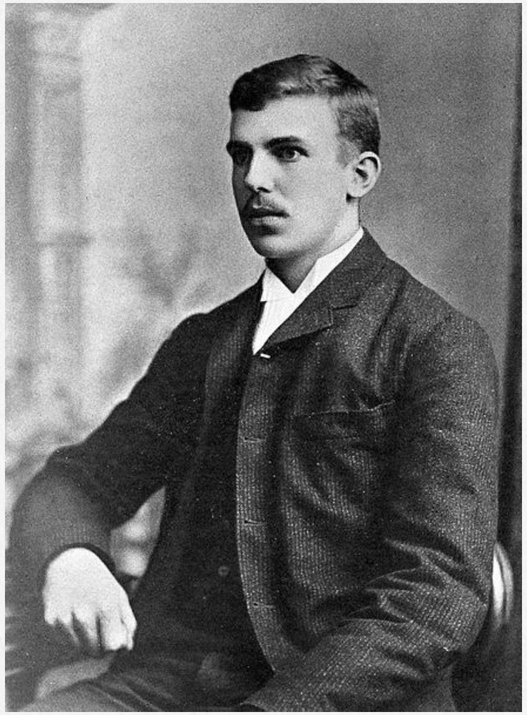
Plum pudding model

In **1897**, Thomson showed that **cathode rays** were composed of previously **unknown negatively charged particles ("corpuscles").**

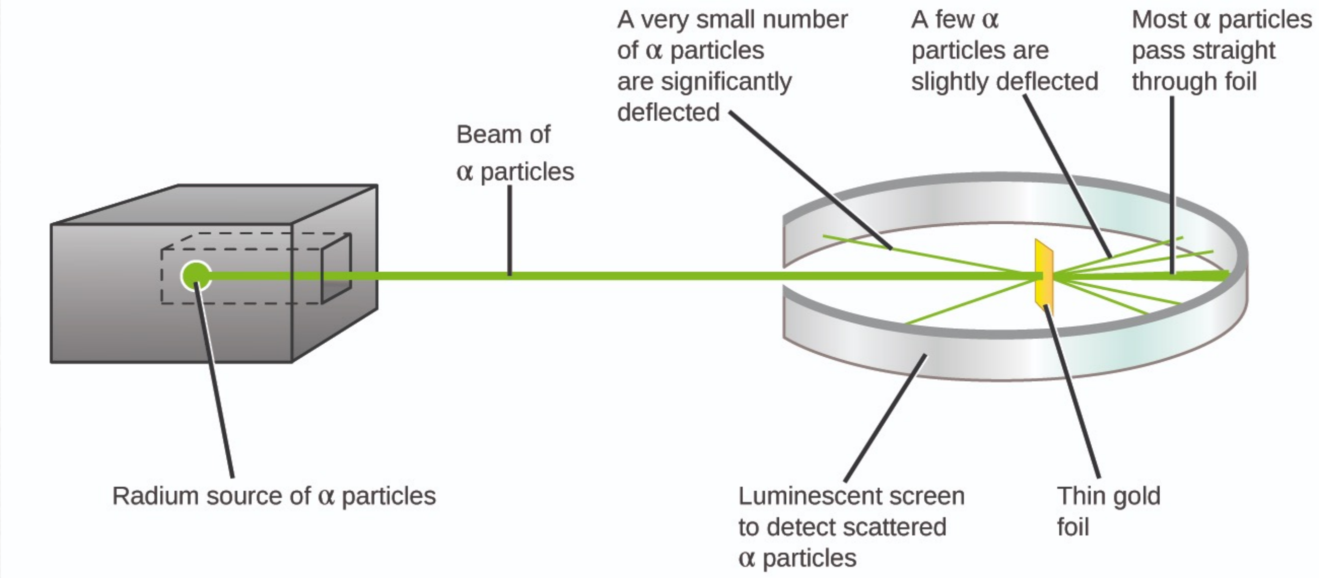
George Johnstone Stoney **1891 Electron**

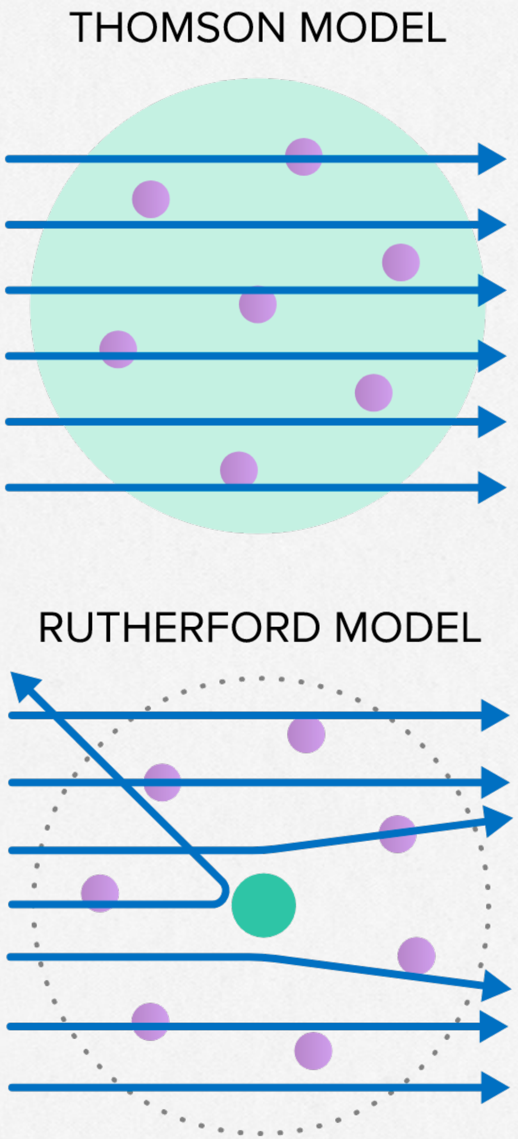
Electron

The gold foil experiment



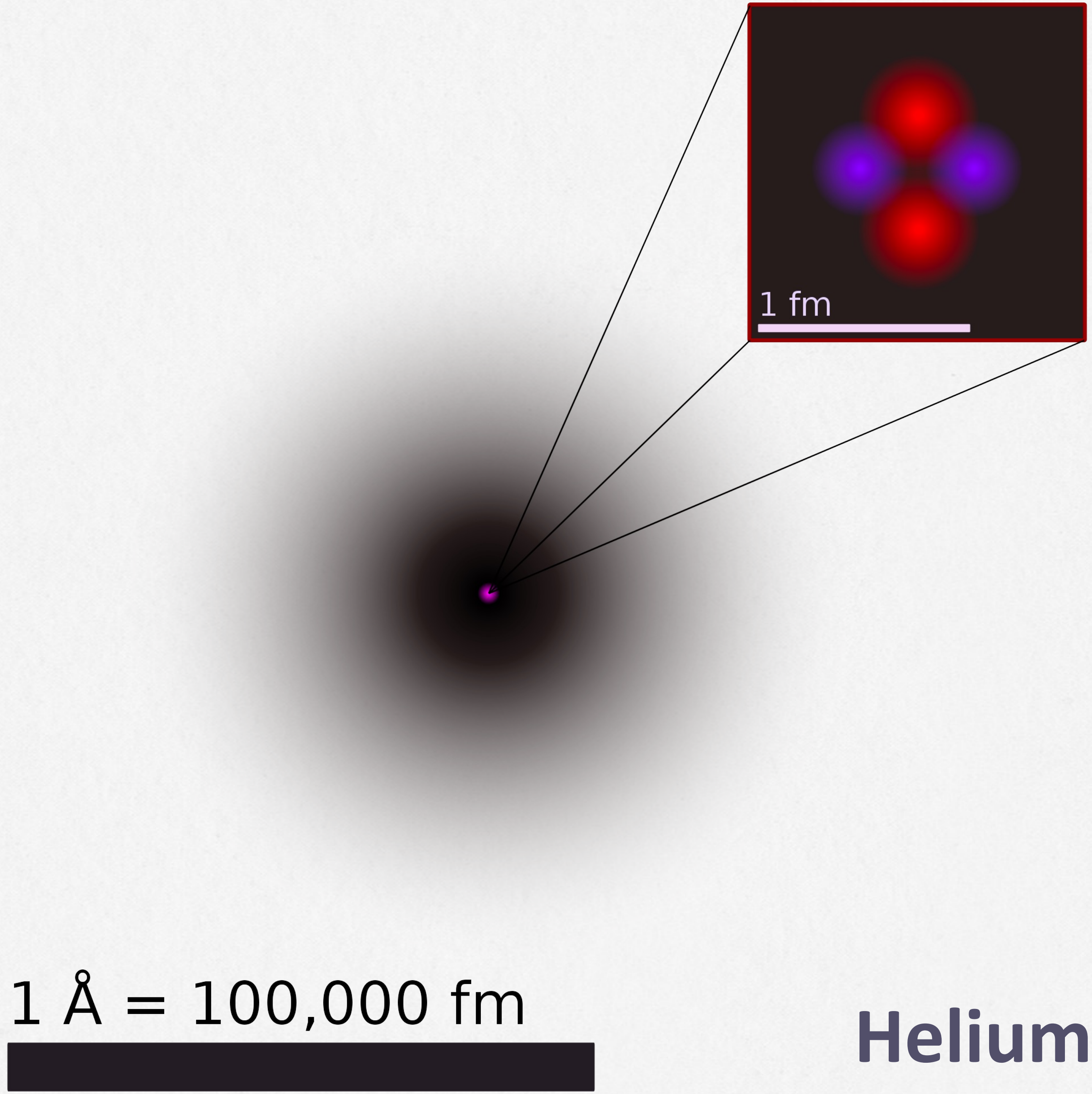
Ernest Rutherford
(30.8.1871 – 30.10.1937)
New Zealand born British physicist
Nobel Prize in Chemistry (1908)





Father of nuclear physics

Electron

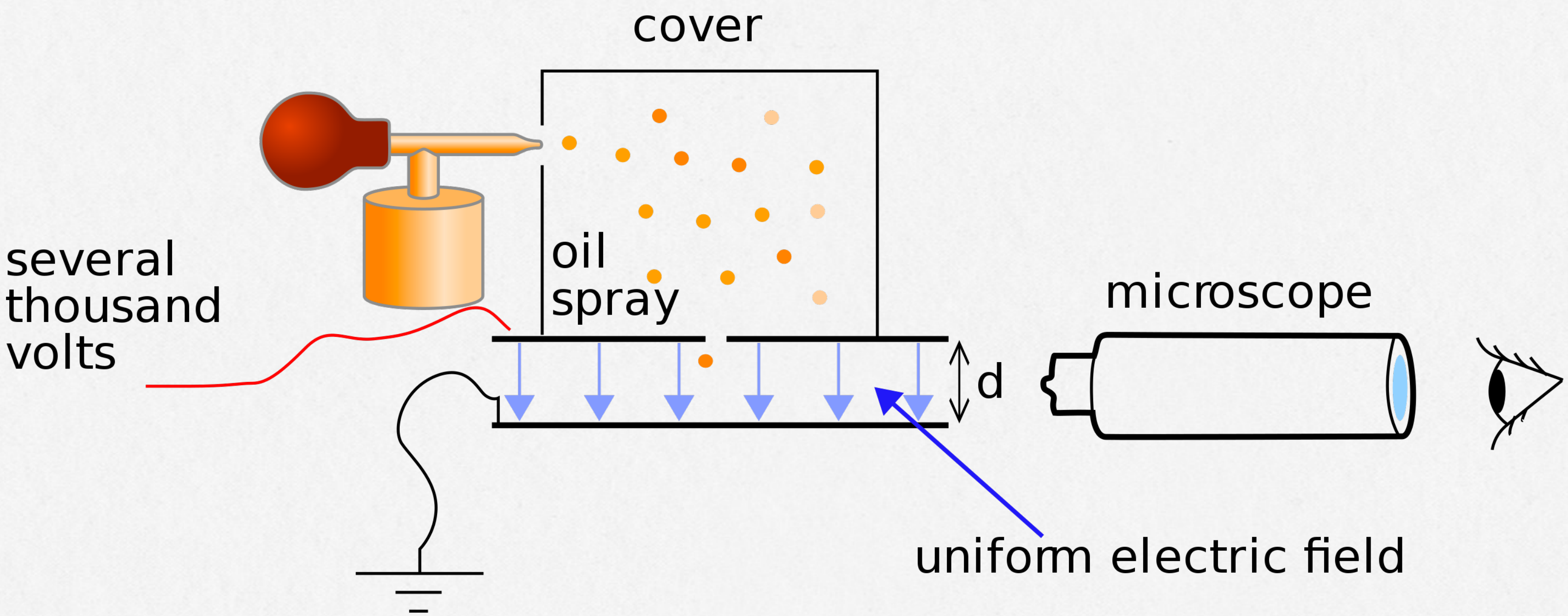


Helium Atom

Electron

Oil drop experiment

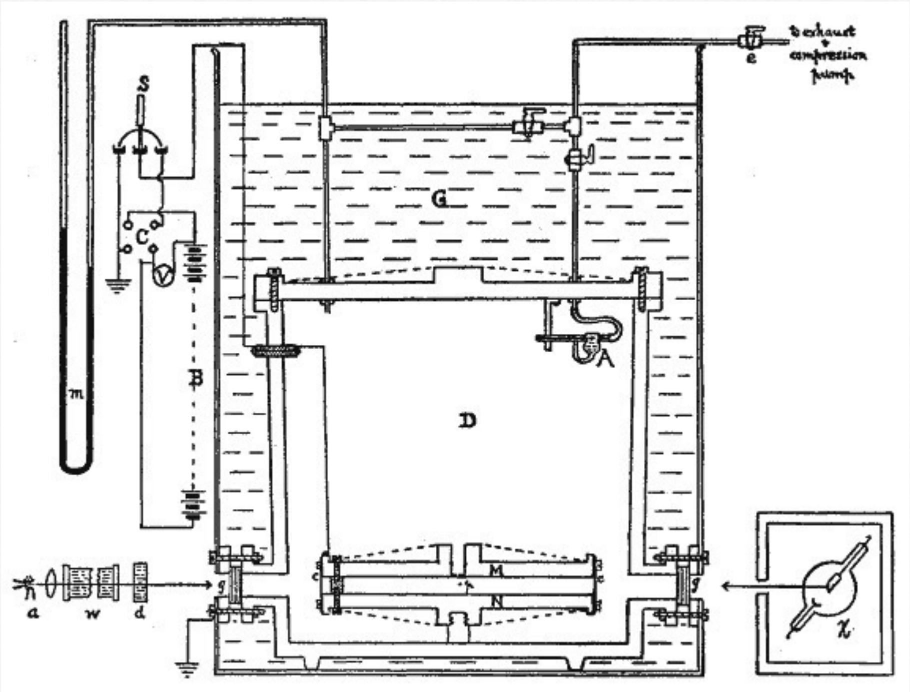
Robert Andrews Millikan
(22.03.1868 – 19.12.1953)
Nobel Prize in 1923



Determination of electron charge

Electron

Oil drop experiment



Robert Andrews Millikan
(22.03.1868 – 19.12.1953)
Nobel Prize in 1923

Determination of electron charge

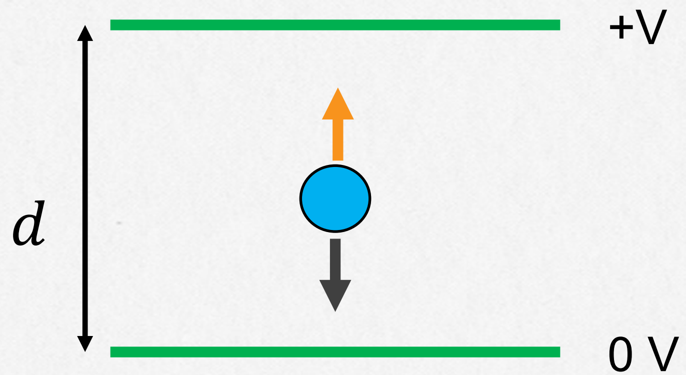
Electron

Question?

How do the oil drops become charged?

Electron

Stationary Electron



Where do the forces belong on the diagram?

Balancing Forces:

$$F_g = F_E$$

$$mg = q\frac{V}{d}$$

Force due to gravity: ?

$$F_g = mg$$

Force due to electric field: ?

$$F_E = qE = q\frac{V}{d}$$

Question: Which of the above quantities would be hard to measure?

Electron

Stationary Electron

Mass!

How would we get around this problem? Any ideas?

Use density!

Density Equation: $\rho = {}^{m}/_{V}$ *V = volume*

- $m = \rho V$

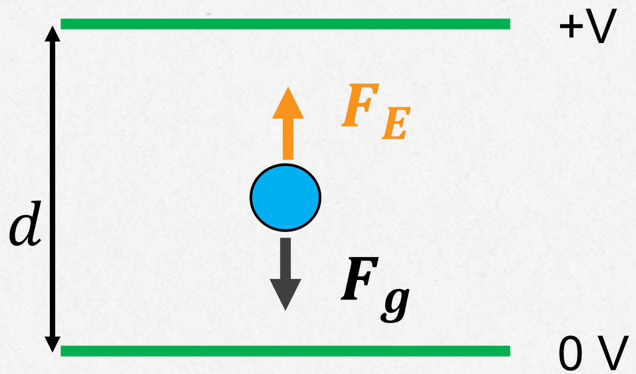
Volume of a spherical oil droplet?

$$V = \frac{4}{3}\pi r^3$$

Therefore mass: $m = \frac{4}{3}\pi \rho r^3$

Electron

Stationary Electron



$$F_g = F_E$$

$$mg = q\frac{V}{d}$$

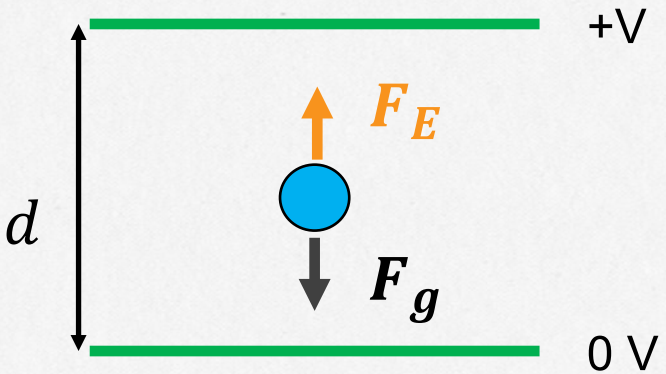
$$\frac{4}{3}\pi g\rho r^3 = q\frac{V}{d}$$

$$m = \frac{4}{3}\pi\rho r^3$$

Question: Are there any other forces to consider?

Electron

Stationary Electron



$$F_a = m_{air} g$$

$$F_a = \frac{4}{3} \pi g \rho_{air} r^3$$

Question: Are there any other forces to consider?

Electron

Stationary Electron

- We now have:

$$F_g = F_a + F_E$$

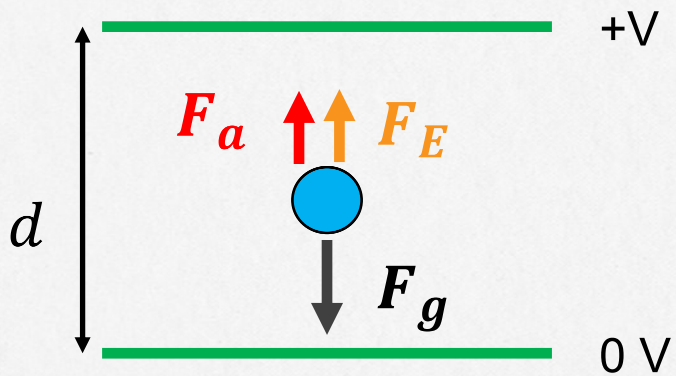
$$\frac{4}{3}\pi g \rho_{oil} r^3 = \frac{4}{3}\pi g \rho_{air} r^3 + q\frac{V}{d}$$

This can easily be solved for q to obtain:

$$q = \frac{{}^4/_3\,\pi(\rho_{oil} - \rho_{air}) g r^3 d}{V}$$

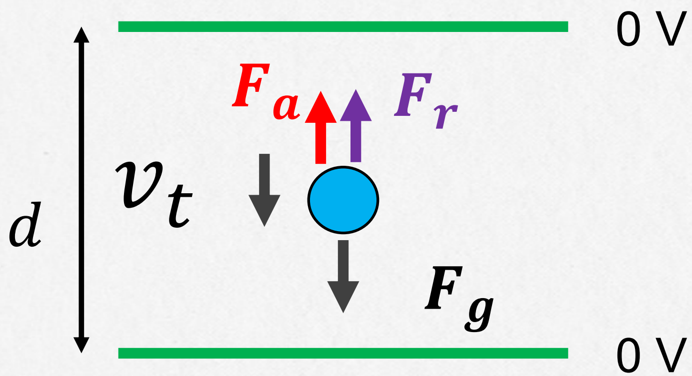
Task: Try to confirm this result for yourselves

Question: Which of these quantities would be hard to measure?



Electron

Moving Electron



- The radius r. To get around this, we use stokes law.

$$F_r = 6\pi\eta r v$$

- At terminal velocity, this is equal to the weight of the drop

$$(m_{oil} - m_{air})g = 6\pi\eta r v$$

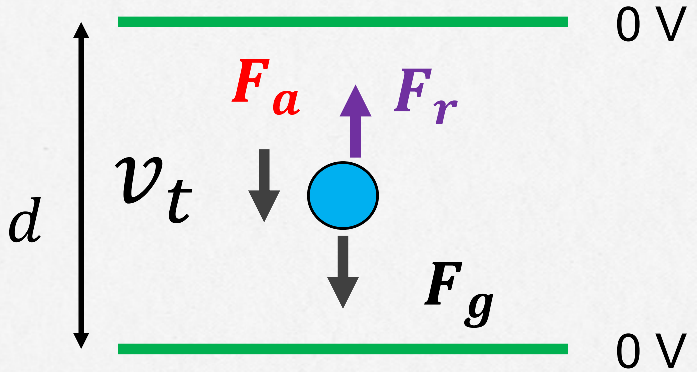
- Remember: η is the viscosity of air

  v is the terminal velocity of the oil drop

Electron

Moving Electron

$$(m_{oil} - m_{air})g = \frac{4}{3}\pi(p_{oil} - p_{air})gr^3$$



$$(m_{oil} - m_{air})g = 6\pi\eta r v$$

$$r = 3\sqrt{\frac{\eta v_t}{2(p_{oil} - p_{air})g}}$$

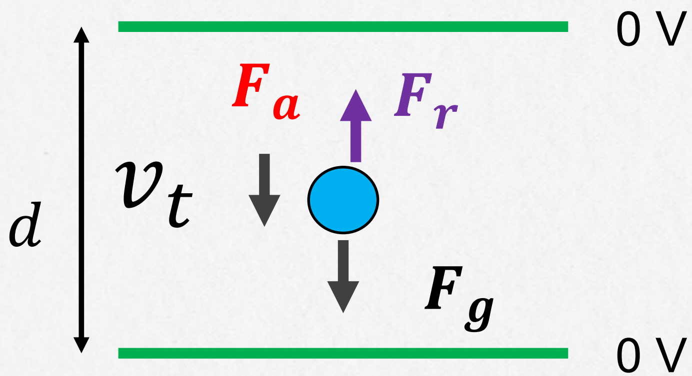
Electron

Moving Electron

$$q = \frac{{}^4/_3\,\pi(\rho - \rho_{air})gr^3 d}{V}$$

$$r = 3\sqrt{\frac{\eta v_t}{2(p_{oil} - p_{air})g}}$$

How to measure v_t?



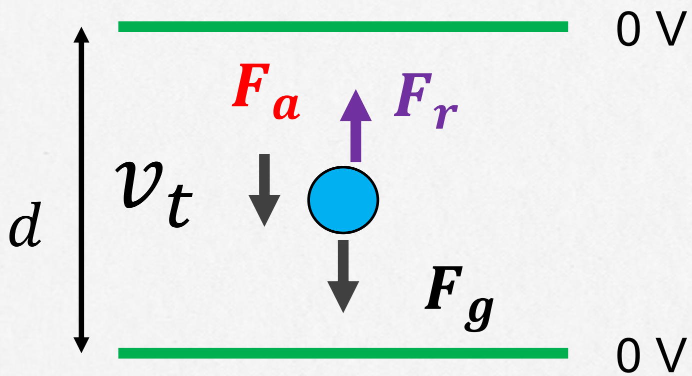
$$q = \frac{9\pi d}{V} \times \sqrt{\frac{2\eta^3 v_t^3}{(\rho_{oil} - \rho_{air})g}}$$

Now we can measure all quantities easily.

Electron

Moving Electron

$$\boldsymbol{v_t = s/t}$$



$$q = \frac{9\pi d}{V} \times \sqrt{\frac{2\eta^3 v_t^3}{(\rho_{oil} - \rho_{air})g}}$$

$$= \frac{t^{-3/2}}{V} \times 9\pi d \sqrt{\frac{2\eta^3 s^3}{(\rho_{oil} - \rho_{air})g}}$$

Air is not continuous

$$\eta' = \frac{\eta}{1 + \frac{b}{pr}} l/t$$

Electron

Values of constants

- air viscosity, η = 1.83 $\times$ 10^{-5} kg/(m·s)
- oil density, ρ_{oil} = 981 kg/m³ at 20°C
- air density, ρ_{air} = 1.30 kg/m³ at 20°C
- plate spacing, d = 5.00 $\times$ 10^{-3} m
- Viscosity coefficient, b = 8.23 $\times$ 10^{-3} N/m
- Pressure p=1.01 $\times$ 10^{5} Pa

$$q = \frac{9\pi d}{V} \times \sqrt{\frac{2\eta^3 v_t^3}{(\rho_{oil} - \rho_{air})g}}$$

$$= \frac{t^{-3/2}}{V} \times 9\pi d \sqrt{\frac{2\eta^3 s^3}{(\rho_{oil} - \rho_{air})g}}$$

Air is not continuous

$$\eta' = \frac{\eta}{1 + \frac{b}{pr}} l/t$$

Electron

Data Recording

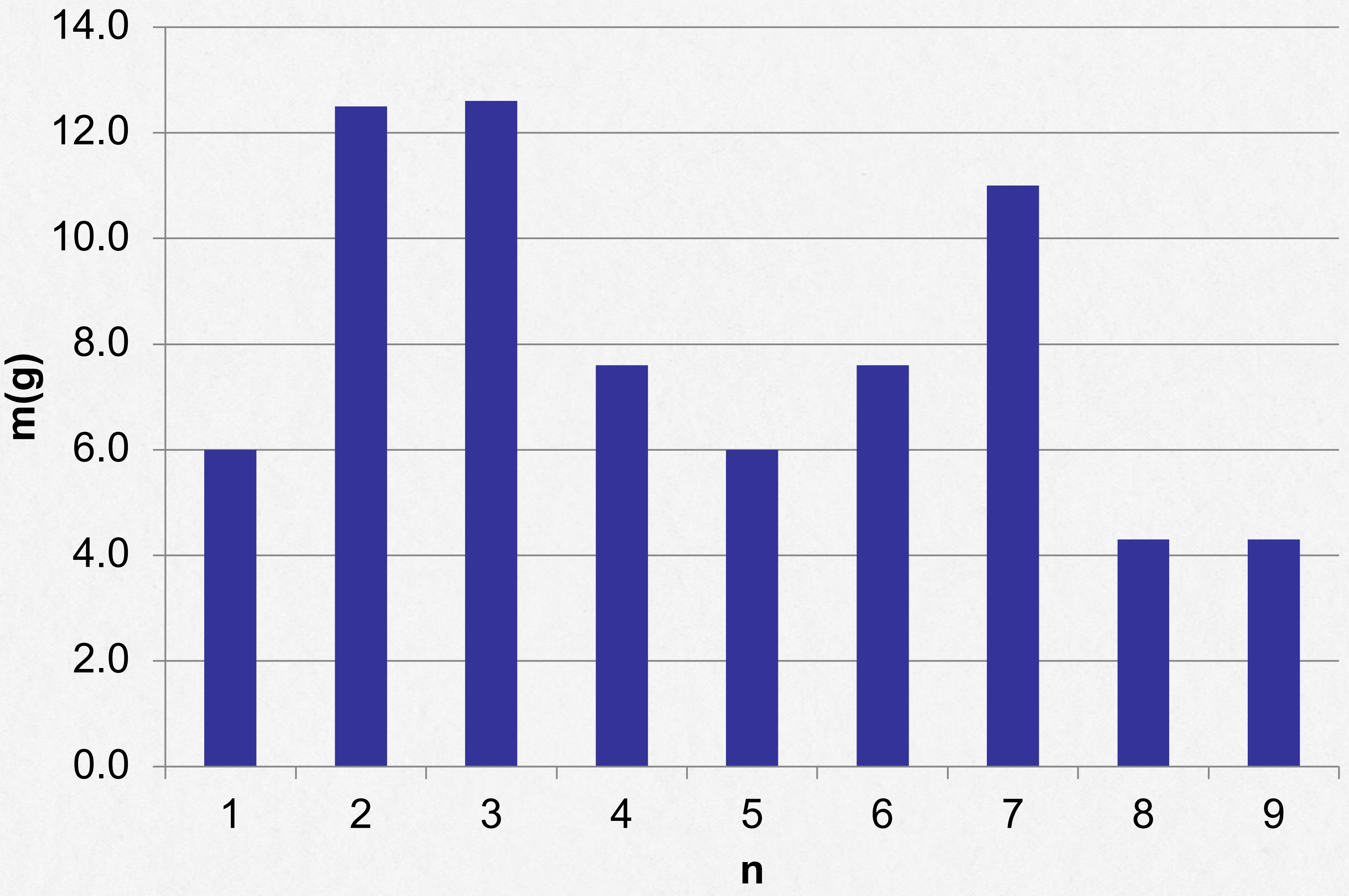
Appendix Table I: Experimental Raw Data for Millikan's Oildrop Experiment

Drop number	Balance voltage, V(V)	Falling time, t(s)	Charge, $q(\times 10^{-19}\text{C})$
1			
2			
3			
4			
5			

Electron

Data Analysis

Envelope (n)	m/g	#cards
1	6.0	?
2	12.5	?
3	12.6	?
4	7.6	?
5	6.0	?
6	7.6	?
7	11.0	?
8	4.3	?
9	4.3	?

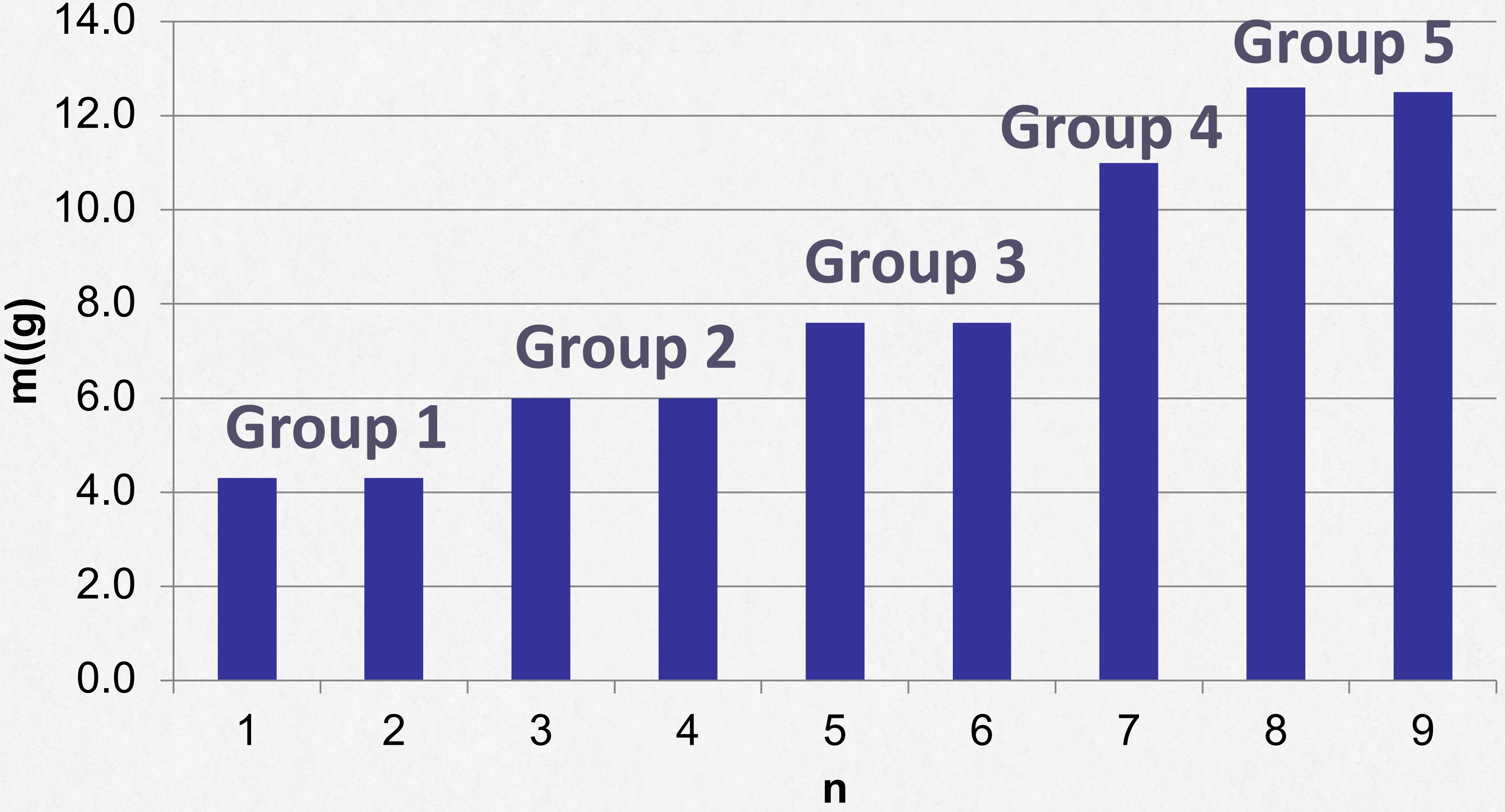


Electron

Data Analysis

Sort B low to high; renumber

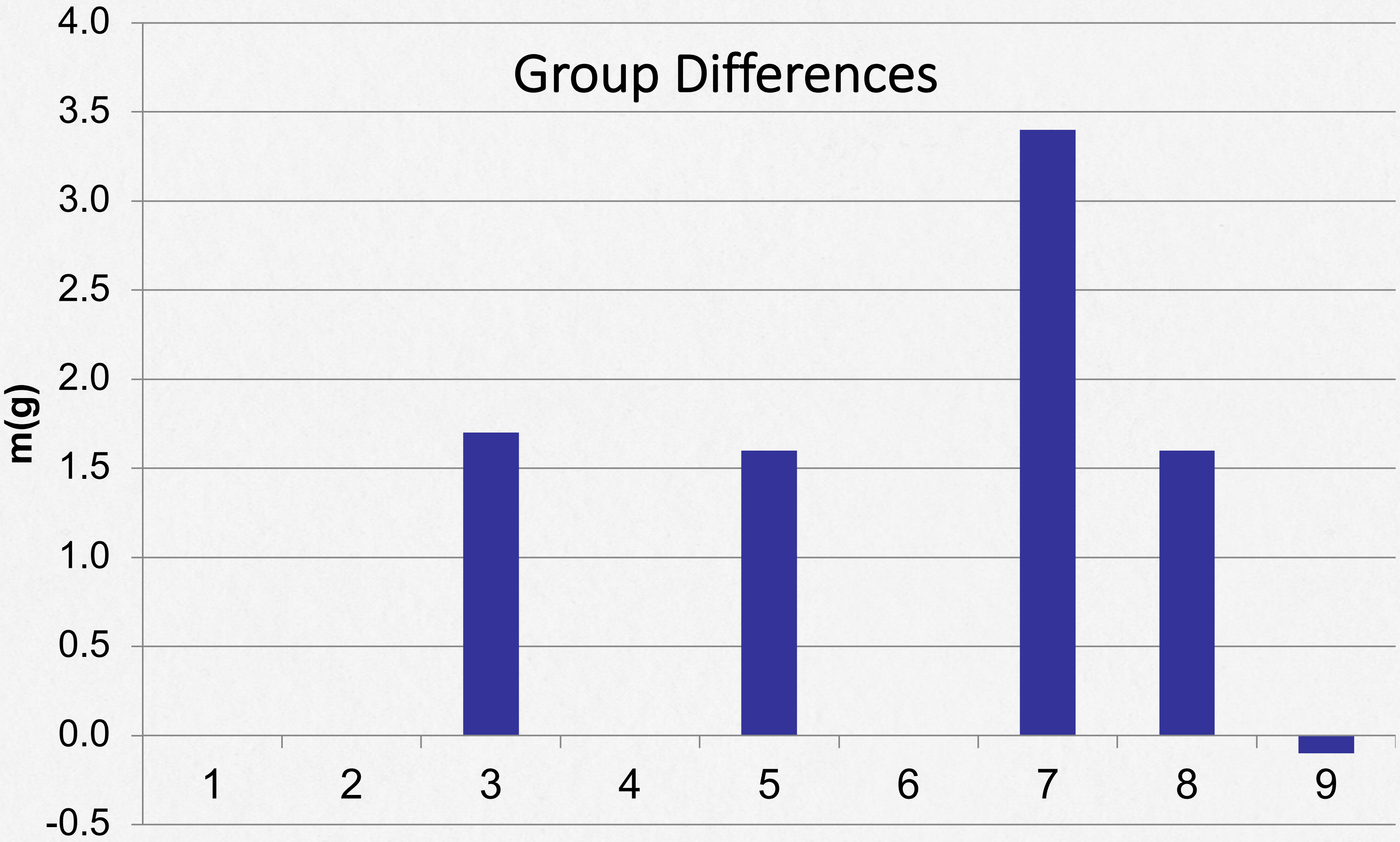
New#	m/g
1	4.3
2	4.3
3	6.0
4	6.0
5	7.6
6	7.6
7	11.0
8	12.6
9	12.5



Data are in groups.

Electron

Data Analysis



Increment between sets are each about 1.7 g.
This is the mass of one unit.(1 card in this case).

Electron

Data Analysis

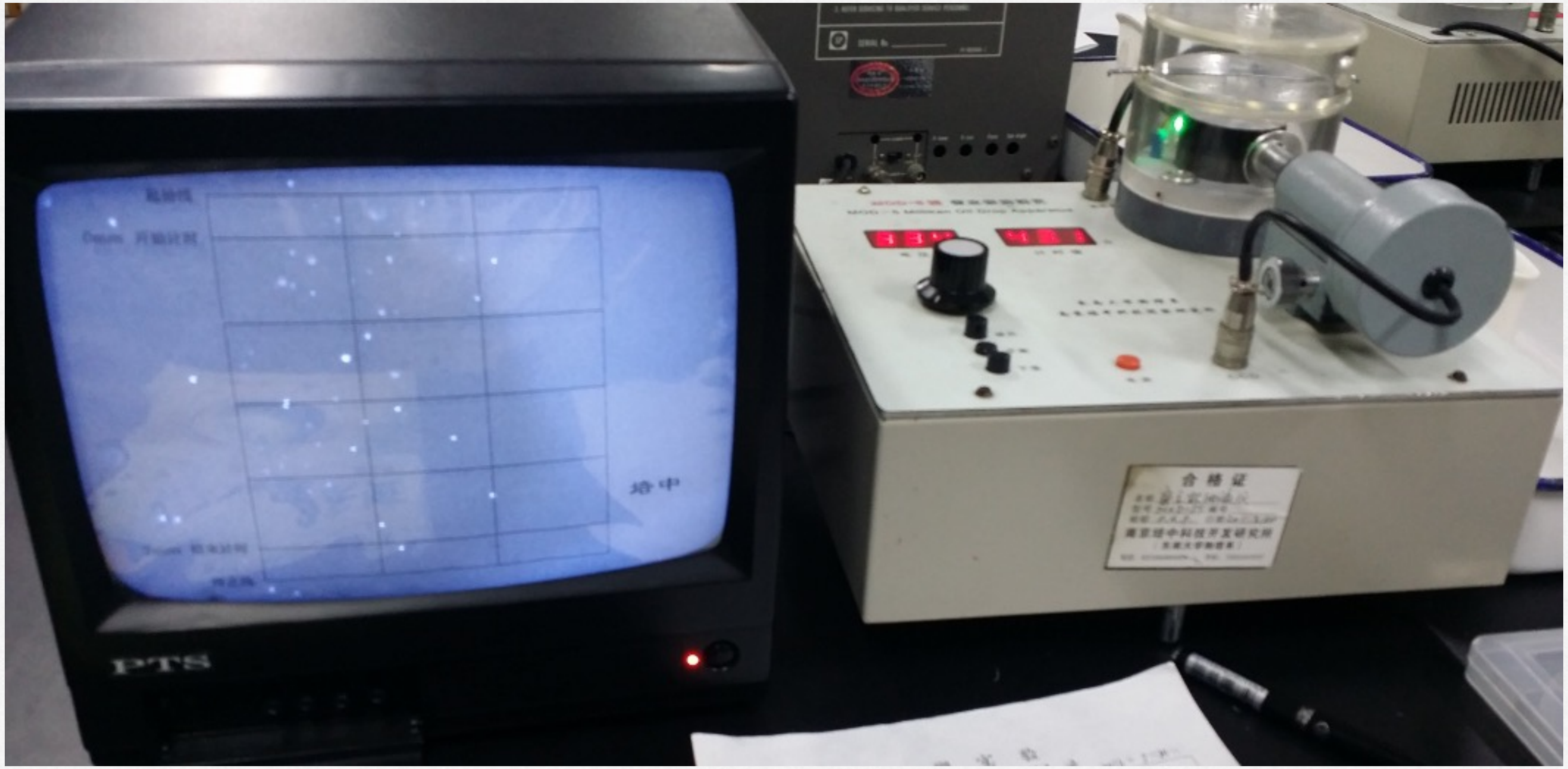
No#	q/c
1	a
2	b
3	c
4	d
5	e
6	f
7	g
8	h
9	i

$q = ne$

How to find e?

Electron

Time for fun!



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THANK YOU !