实验日期 2020.11.17 组号 B4 预习成绩 总成绩

实验（九）电子电荷测定——密立根油滴法

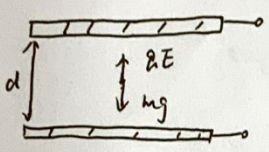
一. 实验目的

① 观察带电油滴在重力场及电场中运动规律

② 选取合适油滴，测定其电荷值 q

二. 实验原理

③ 求电子电荷 e，与公认值比较，作出适当结论。



将油滴经喷雾器喷出，细微油滴易摩擦起电，且 $q=ne$，调整电压极值和电压大小，使电场力与重力平衡，有 $mg=q\frac{U_n}{d} \Rightarrow q=\frac{mgd}{U_n}$

又因 $q=ne$ 故对同一油滴若其带电量为 $q_1 \cdots q_n \cdots$ 则其平衡时电压 $U_{n1} \cdots U_{nn} \cdots$ 为离散值，故元电荷电量 e 可由 $q_1, q_2, q_3 \cdots$ 的最大公约数得出。由于油滴质量极小，只能间接测量。球状油滴有 $m=\frac{4}{3}\pi\rho a^3$，在空气中下落时所受阻力 $F_2=6\pi a\eta v$，重力为 $F_1=\frac{4}{3}\pi a^3\rho' g$，故有

$\frac{4}{3}\pi a^3\rho g=\frac{4}{3}\pi a^3\rho' g+6\pi\eta a v_s$ 得 $a=\sqrt{\frac{9\eta v_s}{2g(\rho-\rho')}}$ 由于 $\rho \gg \rho'$ 故 $a=\sqrt{\frac{9\eta v_s}{2g\rho}}$

将 F_2 修正为 $F_2=\frac{6\pi a\eta v_s}{1+\frac{b}{pa}} \Rightarrow a=\sqrt{\frac{9\eta v_s}{2g\rho(1+\frac{b}{pa})}} \Rightarrow m=\frac{4\pi}{3}\rho\left(\frac{9\eta v_s}{2g\rho(1+\frac{b}{pa})}\right)^{3/2}$

故有 $q=\frac{18\pi}{\sqrt{2g\rho}}\frac{d}{U_n}\left(\frac{\eta v_s}{1+\frac{b}{pa}}\right)^{3/2}$，又有 $v_s=\frac{l}{t}$ 故 $a=\sqrt{\frac{9\eta l}{2g\rho t}}$

得 $q=\frac{18\pi}{\sqrt{2g\rho}}\frac{d}{U_n}\left(\frac{nl}{t(1+\frac{b}{p}\sqrt{\frac{2g\rho t}{9\eta l}})}\right)^{3/2}$ 可得 q 的值。

三. 数据处理

$$q = \frac{18\pi}{\sqrt{2\rho g}} \frac{d}{U_n} \left(\frac{\eta L}{t\left(1+\frac{b}{P_N\sqrt{\frac{2\rho g t}{\eta L}}}\right)} \right)^{3/2} = \frac{1.023\times10^{-14}}{U_n\left(t\left(1+0.022\sqrt{P_N t}\right)\right)^{3/2}}$$

$$q_{11} = \frac{1.023\times10^{-14}}{167\times\left(19.85\left(1+0.022\sqrt{19.85}\right)\right)^{3/2}} = 6.020\times10^{-19}\ C$$

$$q_{12} = \frac{1.023\times10^{-14}}{167\times\left(19.50\left(1+0.022\sqrt{19.50}\right)\right)^{3/2}} = 6.190\times10^{-19}\ C$$

$$q_{13} = \frac{1.023\times10^{-14}}{167\times\left(19.49\left(1+0.022\sqrt{19.49}\right)\right)^{3/2}} = 6.195\times10^{-19}\ C$$

$$q_{14} = \frac{1.023\times10^{-14}}{167\times\left(19.88\left(1+0.022\sqrt{19.88}\right)\right)^{3/2}} = 6.006\times10^{-19}\ C$$

$$q_{15} = \frac{1.023\times10^{-14}}{167\times\left(19.97\left(1+0.022\sqrt{19.97}\right)\right)^{3/2}} = 5.964\times10^{-19}\ C$$

$$q_{31} = \frac{1.023\times10^{-14}}{194\times\left(10.29\left(1+0.022\sqrt{10.29}\right)\right)^{3/2}} = 1.442\times10^{-18}\ C$$

$$q_{32} = \frac{1.023\times10^{-14}}{194\times\left(10.35\left(1+0.022\sqrt{10.35}\right)\right)^{3/2}} = 1.429\times10^{-18}\ C$$

$$q_{33} = \frac{1.023\times10^{-14}}{194\times\left(10.58\left(1+0.022\sqrt{10.58}\right)\right)^{3/2}} = 1.381\times10^{-18}\ C$$

$$q_{34} = \frac{1.023\times10^{-14}}{195\times\left(10.59\left(1+0.022\sqrt{10.59}\right)\right)^{3/2}} = 1.372\times10^{-18}\ C$$

$$q_{35} = \frac{1.023\times10^{-14}}{195\times\left(10.50\left(1+0.022\sqrt{10.50}\right)\right)^{3/2}} = 1.391\times10^{-18}\ C$$

$$q_{41} = \frac{1.023\times10^{-14}}{130\times\left(22.49\left(1+0.022\sqrt{22.49}\right)\right)^{3/2}} = 6.358\times10^{-19}\ C$$

$$q_{42} = \frac{1.023\times10^{-14}}{130\times\left(22.97\left(1+0.022\sqrt{22.97}\right)\right)^{3/2}} = 6.150\times10^{-19}\ C$$

$$q_{43} = \frac{1.023\times10^{-14}}{130\times\left(23.10\left(1+0.022\sqrt{23.10}\right)\right)^{3/2}} = 6.096\times10^{-19}\ C$$

$$q_{44} = \frac{1.023\times10^{-14}}{130\times\left(23.05\left(1+0.022\sqrt{23.05}\right)\right)^{3/2}} = 6.117\times10^{-19}\ C$$

$$q_{45} = \frac{1.023\times10^{-14}}{130\times\left(23.14\left(1+0.022\sqrt{23.14}\right)\right)^{3/2}} = 6.079\times10^{-19}\ C$$

$$E_{q_n} = \sqrt{\left(\frac{\partial \ln q}{\partial U_n}\right)^2 (U_{Un})^2 + \left(\frac{\partial \ln q}{\partial t}\right)^2 (U_t)^2} = \sqrt{\left(\frac{1}{U_n}\right)^2 (U_{Un})^2 + \frac{9}{4}\left(\frac{1}{t}+\frac{1}{\sqrt{t}(\sqrt{t}+45.525)}\right)^2 (U_t)^2}$$

$$\bar{t}_1 = \frac{1}{5}(19.85+19.50+19.49+19.88+19.97) = 19.74\,s$$

$$\bar{t}_3 = \frac{1}{5}(10.29+10.35+10.58+10.59+10.50) = 10.46\,s$$

$$\bar{t}_4 = \frac{1}{5}(22.49+22.97+23.10+23.05+23.14) = 22.95\,s$$

$$u_{t1} = \sqrt{\frac{1}{5\times4}\left[(19.85-19.74)^2+(19.50-19.74)^2+(19.49-19.74)^2+(19.88-19.74)^2+(19.97-19.74)^2\right]} = 0.10\,s$$

$$u_{t3} = \sqrt{\frac{1}{5\times4}\left[(10.29-10.46)^2+(10.35-10.46)^2+(10.58-10.46)^2+(10.59-10.46)^2+(10.50-10.46)^2\right]} = 0.06\,s$$

$$u_{t4} = \sqrt{\frac{1}{5\times4}\left[(22.49-22.95)^2+(22.97-22.95)^2+(23.10-22.95)^2+(23.05-22.95)^2+(23.14-22.95)^2\right]} = 0.12\,s$$

$u_{un1} = 0$ ~~u_{un3}~~ $u_{un4} = 0$

$$\bar{u}_{n3} = \frac{1}{5}(194+194+194+195+195) = 194\,V$$

$$u_{un3} = \sqrt{\frac{1}{5\times4}\left[(194-194)^2+(194-194)^2+(194-194)^2+(195-194)^2+(195-194)^2\right]} = 0.3\,V$$

$$E_{q1} = \sqrt{\frac{1}{167}\times0^2+\frac{9}{4}\left(\frac{1}{19.74}+\frac{1}{\sqrt{19.74}\left(\sqrt{19.74}+45.525\right)}\right)^2(0.10)^2} = 0.9\%$$

$$E_{q3} = \sqrt{\frac{1}{194}\times0.3^2+\frac{9}{4}\left(\frac{1}{10.46}+\frac{1}{\sqrt{10.46}\left(\sqrt{10.46}+45.525\right)}\right)^2(0.06)^2} = 3\%$$

$$E_{q4} = \sqrt{\frac{1}{130}\times0^2+\frac{9}{4}\left(\frac{1}{22.95}+\frac{1}{\sqrt{22.95}\left(\sqrt{22.95}+45.525\right)}\right)^2(0.12)^2} = 0.9\%.$$

$$\bar{e}_1 = \frac{1}{5}(1.505\times10^{-19}+1.548\times10^{-19}+1.549\times10^{-19}+1.502\times10^{-19}+1.491\times10^{-19}) = 1.519\times10^{-19}\,C$$

$$\bar{e}_3 = \frac{1}{5}(1.602\times10^{-19}+1.588\times10^{-19}+1.534\times10^{-19}+1.544\times10^{-19}+1.546\times10^{-19}) = 1.559\times10^{-19}\,C$$

$$\bar{e}_4 = \frac{1}{5}(1.590\times10^{-19}+1.538\times10^{-19}+1.524\times10^{-19}+1.529\times10^{-19}+1.520\times10^{-19}) = 1.540\times10^{-19}\,C.$$

$$E_1 = \frac{|1.519\times10^{-19}-1.602\times10^{-19}|}{1.602\times10^{-19}} = 5.2\%$$

$$E_2 = \frac{|1.559\times10^{-19}-1.602\times10^{-19}|}{1.602\times10^{-19}} = 2.7\%$$

$$E_3 = \frac{|1.540\times10^{-19}-1.602\times10^{-19}|}{1.602\times10^{-19}} = 3.9\%$$

$$\bar{e} = \frac{1}{3}(\bar{e}_1+\bar{e}_3+\bar{e}_4) = \frac{1}{3}\times(1.519\times10^{-19}+1.559\times10^{-19}+1.540\times10^{-19}) = 1.539\times10^{-19}\,C.$$

$$E = \frac{|1.539\times10^{-19}-1.602\times10^{-19}|}{1.602\times10^{-19}} = 3.9\%$$

四. 实验结论及现象分析

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实验测得油滴电荷量为 $1.539\times10^{-19}C$，与理论值的百分误差为 3.9%.

五. 讨论问题

① 当跟踪某一油滴时，原来清晰的像变模糊了，可能是什么原因？

答：可能是油滴在沿镜筒方向上发生了位移.

② 由于油的挥发，油滴质量会不断下降，当长时间跟踪测量同一个油滴时，会使测量量哪些量发生变化.

答：由于 $mg = qE = q\frac{U}{d}$，当质量下降时平衡电压会下降.

当质量下降时体积也下降，使空气浮力和黏滞摩擦阻力下降，故下落时间也会下降.

实验现象观察与原始数据记录

油滴序号	测量次数 i	平衡电压 U_{in}(V)	下落时间 t(s)	油滴电荷 q_i(C)	q_i/e	q_i/N
1	1	167	19.85	6.020×10^{-19}	4	1.505×10^{-19}
	2	167	19.50	6.190×10^{-19}	4	1.548×10^{-19}
	3	167	19.49	6.195×10^{-19}	4	1.549×10^{-19}
	4	167	19.88	6.006×10^{-19}	4	1.502×10^{-19}
	5	167	19.97	5.964×10^{-19}	4	1.491×10^{-19}
2	1	~~143~~ 143 ~~254~~ ~~360~~ ~~459~~	~~39.48~~ ~~27.99~~ 19.17			
	2	143 ~~254~~ ~~360~~	~~39.51~~ ~~38.19~~ 18.21			
	3	143 ~~254~~	~~39.65~~ ~~38.20~~ 18.88			
	4	143 ~~254~~	~~39.32~~ ~~38.01~~ 19.10			
	5	143 ~~254~~	~~38.97~~ ~~38.05~~ 18.54			
3	1	194	10.29	1.442×10^{-18}	9	1.602×10^{-19}
	2	194	10.35	1.429×10^{-18}	9	1.588×10^{-19}
	3	194	10.58	1.381×10^{-18}	9	1.534×10^{-19}
	4	~~194~~ 195	10.59	1.372×10^{-18}	9	1.524×10^{-19}
	5	~~194~~ 195	10.50	1.391×10^{-18}	9	1.546×10^{-19}
4	1	130	22.49	6.358×10^{-19}	4	1.590×10^{-19}
	2	130	22.97	6.150×10^{-19}	4	1.538×10^{-19}
	3	130	23.10	6.096×10^{-19}	4	1.524×10^{-19}
	4	130	23.05	6.117×10^{-19}	4	1.529×10^{-19}
	5	130	23.14	6.079×10^{-19}	4	1.520×10^{-19}

取第 1 3 4 组数据

学生	姓名	学号	日期
签字			

教师	姓名
签字	