The Millikan Oil Drop Experiment

Luke Renchik
Jordan Swanson
Yousif Batroos
Kelvin De Villena
Leo Gorges
Raffy Karoumi

March 14, 2023

Contents

1 Purpose **3**

2 Data **5**

3 Calculations **19**

4 Results **21**

5 Conclusion **25**

6 Appendix **26**

List of Figures

1.1 A Diagram of Millikan's Oil Apparatus. Jason, Martineau, *The Millikan Oil Drop Experiment* 4

3.1 A FBD for Oil Drop in Freefall. 19
3.2 A FBD for Oil Drop in Slow Rise. 20

4.1 Calculated Elementary Charge of Electrons 23
4.2 Calculated Electrons in each Oil Drop 24

Purpose

The purpose of this experiment was to infer the charge on a single electron.

Procedure

Millikan's Oil Drop experiment was a landmark study that led to the discovery of the elementary charge of an electron. Robert Millikan's method involved measuring the electric charge on tiny droplets of oil suspended in an electric field, using a device known as the Millikan oil-drop apparatus, a depiction of this device can be found in Figure 1. By using multiple oil drops of different sizes and masses, Millikan was able to obtain a range of values for the electric charge.

The experiment worked by shining a light on the oil droplets, allowing Millikan to observe the droplets and measure their rate of fall in the electric field. By adjusting the strength of the electric field, Millikan was able to balance the force of gravity and the electric force on each droplet, making it appear to be suspended in mid-air and move between the positive and negatively charged plates. This allowed him to determine the electric charge on each droplet by calculating the electric field strength required to balance the forces.

Since the electric charge on each droplet was a multiple of the elementary charge of an electron, Millikan was able to determine the value of the elementary charge by dividing the charge on each droplet by the number of electrons he believed were present on it. By repeating the experiment multiple times with different droplets, Millikan was able to obtain a range of values for the elementary charge, and from this data, he was able to calculate a precise value for the elementary charge of an electron.

The experimental data used in this experiment was gathered using a computer program that simulated the experimental procedure and results of Millikan's famous experiment.

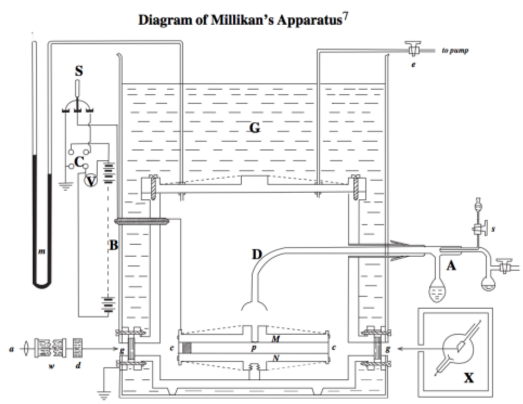

Figure 1.1: A Diagram of Millikan's Oil Apparatus. Jason, Martineau, *The Millikan Oil Drop Experiment*

Data

In this lab report, data is presented from an experiment conducted on the Millikan Oil Drop experiment, using two methods of data collection. The first method involved the use of a highly efficient computer program that allowed for the collection of a large number of trial oil droplets. The second method used a physical apparatus, which posed several challenges due to the unpredictable nature of the oil droplets inside the canister. These droplets tended to disappear or get lost during the data collection process, making the experiment challenging but informative. Despite the challenges, valuable data was obtained from both methods, and important conclusions about the elementary charge of an electron were drawn.

Drop 1: Freefall		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	22.79
2	2.90×10^-3	23.13
3	2.90×10^-3	22.35
4	2.90×10^-3	21.97
5	2.90×10^-3	22.97
6	2.90×10^-3	23.03
7	2.90×10^-3	22.46
8	2.90×10^-3	22.48
9	2.90×10^-3	22.39
10	2.90×10^-3	22.94
11	2.90×10^-3	22.37

Table 2.1: Measured Times to Travel 2.90×10^-3 m

Drop 1: Slowrise - 249.4 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	59.03
2	$2.90 \times 10^{-}3$	59.35
3	$2.90 \times 10^{-}3$	59.2
4	$2.90 \times 10^{-}3$	57.95
5	$2.90 \times 10^{-}3$	59.3
6	$2.90 \times 10^{-}3$	59.56
7	$2.90 \times 10^{-}3$	59.33
8	$2.90 \times 10^{-}3$	58.69
9	$2.90 \times 10^{-}3$	58.27
10	$2.90 \times 10^{-}3$	58.69
11	$2.90 \times 10^{-}3$	59.05

Table 2.2: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 1: Fastfall - 249.4 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	9.28
2	$2.90 \times 10^{-}3$	9.13
3	$2.90 \times 10^{-}3$	9.38
4	$2.90 \times 10^{-}3$	9.42
5	$2.90 \times 10^{-}3$	9.55
6	$2.90 \times 10^{-}3$	9.32
7	$2.90 \times 10^{-}3$	9.53
8	$2.90 \times 10^{-}3$	9.38
9	$2.90 \times 10^{-}3$	9.47
10	$2.90 \times 10^{-}3$	9.23
11	$2.90 \times 10^{-}3$	9.27

Table 2.3: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 2: Freefall		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	89.68
2	$2.90 \times 10^{-}3$	89.12
3	$2.90 \times 10^{-}3$	90.13
4	$2.90 \times 10^{-}3$	89.45
5	$2.90 \times 10^{-}3$	89.75
6	$2.90 \times 10^{-}3$	89.53
7	$2.90 \times 10^{-}3$	89.88
8	$2.90 \times 10^{-}3$	90.05
9	$2.90 \times 10^{-}3$	89.78
10	$2.90 \times 10^{-}3$	89.15
11	$2.90 \times 10^{-}3$	89.24

Table 2.4: Measured Times to Travel $2.90 \times 10^{-}3$ m

Drop 2: Slowrise - 249.4 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	7.07
2	$2.90 \times 10^{-}3$	7.01
3	$2.90 \times 10^{-}3$	7.01
4	$2.90 \times 10^{-}3$	7.04
5	$2.90 \times 10^{-}3$	6.99
6	$2.90 \times 10^{-}3$	6.99
7	$2.90 \times 10^{-}3$	7.09
8	$2.90 \times 10^{-}3$	6.99
9	$2.90 \times 10^{-}3$	7.01
10	$2.90 \times 10^{-}3$	7.04
11	$2.90 \times 10^{-}3$	7.01

Table 2.5: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 3: Fastfall - 249.4 Volts		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	6.09
2	2.90×10^-3	6.08
3	2.90×10^-3	6.09
4	2.90×10^-3	6.00
5	2.90×10^-3	6.04
6	2.90×10^-3	6.04
7	2.90×10^-3	6.06
8	2.90×10^-3	6.08
9	2.90×10^-3	6.09
10	2.90×10^-3	6.08
11	2.90×10^-3	6.08

Table 2.6: Measured Times to Travel 2.90×10^-3

Drop 3: Freefall		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	90.49
2	2.90×10^-3	90.08
3	2.90×10^-3	89.60
4	2.90×10^-3	89.62
5	2.90×10^-3	89.72
6	2.90×10^-3	89.68
7	2.90×10^-3	89.77
8	2.90×10^-3	89.01
9	2.90×10^-3	89.39
10	2.90×10^-3	89.58
11	2.90×10^-3	90.61

Table 2.7: Measured Times to Travel 2.90×10^-3 m

Drop 3: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	31.80
2	2.90×10^-3	31.69
3	2.90×10^-3	32.35
4	2.90×10^-3	31.90
5	2.90×10^-3	32.54
6	2.90×10^-3	32.01
7	2.90×10^-3	31.84
8	2.90×10^-3	32.13
9	2.90×10^-3	32.22
10	2.90×10^-3	32.49
11	2.90×10^-3	31.98

Table 2.8: Measured Times to Travel 2.90×10^-3

Drop 3: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	18.80
2	2.90×10^-3	18.72
3	2.90×10^-3	18.61
4	2.90×10^-3	18.72
5	2.90×10^-3	18.36
6	2.90×10^-3	18.57
7	2.90×10^-3	18.38
8	2.90×10^-3	18.72
9	2.90×10^-3	18.49
10	2.90×10^-3	19.03
11	2.90×10^-3	18.61

Table 2.9: Measured Times to Travel 2.90×10^-3

Drop 4: Freefall		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	89.32
2	$2.90 \times 10^{-}3$	89.01
3	$2.90 \times 10^{-}3$	89.99
4	$2.90 \times 10^{-}3$	89.85
5	$2.90 \times 10^{-}3$	89.46
6	$2.90 \times 10^{-}3$	88.84
7	$2.90 \times 10^{-}3$	89.78
8	$2.90 \times 10^{-}3$	88.73
9	$2.90 \times 10^{-}3$	89.50
10	$2.90 \times 10^{-}3$	88.87
11	$2.90 \times 10^{-}3$	89.53

Table 2.10: Measured Times to Travel $2.90 \times 10^{-}3$ m

Drop 4: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	99.56
2	$2.90 \times 10^{-}3$	100.50
3	$2.90 \times 10^{-}3$	100.15
4	$2.90 \times 10^{-}3$	99.98
5	$2.90 \times 10^{-}3$	100.12
6	$2.90 \times 10^{-}3$	100.29
7	$2.90 \times 10^{-}3$	99.11
8	$2.90 \times 10^{-}3$	100.22
9	$2.90 \times 10^{-}3$	98.97
10	$2.90 \times 10^{-}3$	100.33
11	$2.90 \times 10^{-}3$	99.73

Table 2.11: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 4: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	30.69
2	$2.90 \times 10^{-}3$	30.49
3	$2.90 \times 10^{-}3$	30.39
4	$2.90 \times 10^{-}3$	30.67
5	$2.90 \times 10^{-}3$	31.57
6	$2.90 \times 10^{-}3$	31.02
7	$2.90 \times 10^{-}3$	31.05
8	$2.90 \times 10^{-}3$	30.67
9	$2.90 \times 10^{-}3$	31.36
10	$2.90 \times 10^{-}3$	31.26
11	$2.90 \times 10^{-}3$	31.02

Table 2.12: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 5: Freefall		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	89.70
2	$2.90 \times 10^{-}3$	89.05
3	$2.90 \times 10^{-}3$	89.49
4	$2.90 \times 10^{-}3$	89.60
5	$2.90 \times 10^{-}3$	89.53
6	$2.90 \times 10^{-}3$	89.83
7	$2.90 \times 10^{-}3$	89.39
8	$2.90 \times 10^{-}3$	89.73
9	$2.90 \times 10^{-}3$	89.49
10	$2.90 \times 10^{-}3$	89.58
11	$2.90 \times 10^{-}3$	90.02

Table 2.13: Measured Times to Travel $2.90 \times 10^{-}3$ m

Drop 5: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	100.24
2	$2.90 \times 10^{-}3$	99.46
3	$2.90 \times 10^{-}3$	99.23
4	$2.90 \times 10^{-}3$	99.74
5	$2.90 \times 10^{-}3$	99.95
6	$2.90 \times 10^{-}3$	100.03
7	$2.90 \times 10^{-}3$	99.67
8	$2.90 \times 10^{-}3$	99.65
9	$2.90 \times 10^{-}3$	99.89
10	$2.90 \times 10^{-}3$	100.05
11	$2.90 \times 10^{-}3$	100.33

Table 2.14: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 5: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	31.01
2	$2.90 \times 10^{-}3$	30.84
3	$2.90 \times 10^{-}3$	30.74
4	$2.90 \times 10^{-}3$	31.06
5	$2.90 \times 10^{-}3$	30.78
6	$2.90 \times 10^{-}3$	30.95
7	$2.90 \times 10^{-}3$	31.10
8	$2.90 \times 10^{-}3$	30.70
9	$2.90 \times 10^{-}3$	30.99
10	$2.90 \times 10^{-}3$	30.93
11	$2.90 \times 10^{-}3$	31.14

Table 2.15: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 6: Freefall		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	90.13
2	2.90×10^-3	89.89
3	2.90×10^-3	89.77
4	2.90×10^-3	89.34
5	2.90×10^-3	89.20
6	2.90×10^-3	89.22
7	2.90×10^-3	89.24
8	2.90×10^-3	89.51
9	2.90×10^-3	89.72
10	2.90×10^-3	89.83
11	2.90×10^-3	89.60

Table 2.16: Measured Times to Travel 2.90×10^-3

Drop 6: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.90×10^-3	32.32
2	2.90×10^-3	32.24
3	2.90×10^-3	31.99
4	2.90×10^-3	31.94
5	2.90×10^-3	32.24
6	2.90×10^-3	32.34
7	2.90×10^-3	32.09
8	2.90×10^-3	32.20
9	2.90×10^-3	31.84
10	2.90×10^-3	32.24
11	2.90×10^-3	32.18

Table 2.17: Measured Times to Travel 2.90×10^-3

Drop 6: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	18.80
2	$2.90 \times 10^{-}3$	18.42
3	$2.90 \times 10^{-}3$	18.74
4	$2.90 \times 10^{-}3$	18.78
5	$2.90 \times 10^{-}3$	18.51
6	$2.90 \times 10^{-}3$	18.59
7	$2.90 \times 10^{-}3$	18.87
8	$2.90 \times 10^{-}3$	18.61
9	$2.90 \times 10^{-}3$	18.38
10	$2.90 \times 10^{-}3$	18.52
11	$2.90 \times 10^{-}3$	19.81

Table 2.18: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 7: Freefall		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	22.48
2	$2.90 \times 10^{-}3$	22.88
3	$2.90 \times 10^{-}3$	22.33
4	$2.90 \times 10^{-}3$	22.25
5	$2.90 \times 10^{-}3$	22.18
6	$2.90 \times 10^{-}3$	22.41
7	$2.90 \times 10^{-}3$	22.58
8	$2.90 \times 10^{-}3$	22.67
9	$2.90 \times 10^{-}3$	22.50
10	$2.90 \times 10^{-}3$	22.39
11	$2.90 \times 10^{-}3$	22.42

Table 2.19: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 7: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	43.17
2	$2.90 \times 10^{-}3$	41.54
3	$2.90 \times 10^{-}3$	41.63
4	$2.90 \times 10^{-}3$	41.30
5	$2.90 \times 10^{-}3$	41.45
6	$2.90 \times 10^{-}3$	41.51
7	$2.90 \times 10^{-}3$	41.62
8	$2.90 \times 10^{-}3$	41.79
9	$2.90 \times 10^{-}3$	41.35
10	$2.90 \times 10^{-}3$	41.34
11	$2.90 \times 10^{-}3$	41.03

Table 2.20: Measured Times to Travel $2.90 \times 10^{-}3$

Drop 7: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.90 \times 10^{-}3$	9.02
2	$2.90 \times 10^{-}3$	8.92
3	$2.90 \times 10^{-}3$	8.85
4	$2.90 \times 10^{-}3$	9.04
5	$2.90 \times 10^{-}3$	8.81
6	$2.90 \times 10^{-}3$	8.56
7	$2.90 \times 10^{-}3$	9.00
8	$2.90 \times 10^{-}3$	8.83
9	$2.90 \times 10^{-}3$	9.25
10	$2.90 \times 10^{-}3$	9.44
11	$2.90 \times 10^{-}3$	9.00

Table 2.21: Measured Times to Travel $2.90 \times 10^{-}3$

PA - Drop 1: Freefall		
Trial	Distance (m)	Time (s)
1	$2.50 \times 10^{-}3$	22.36
2	$2.50 \times 10^{-}3$	25.59
3	$2.50 \times 10^{-}3$	28.35
4	$2.50 \times 10^{-}3$	31.86

Table 2.22: Measured Times to Travel $2.50 \times 10^{-}3$

PA - Drop 1: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.50 \times 10^{-}3$	8.28
2	$2.50 \times 10^{-}3$	7.33
3	$2.50 \times 10^{-}3$	6.77
4	$2.50 \times 10^{-}3$	4.66
5	$2.50 \times 10^{-}3$	4.22
6	$2.50 \times 10^{-}3$	4.45
7	$2.50 \times 10^{-}3$	9.45
8	$2.50 \times 10^{-}3$	6.76

Table 2.23: Measured Times to Travel $2.50 \times 10^{-}3$

PA - Drop 1: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	$2.50 \times 10^{-}3$	4.46
2	$2.50 \times 10^{-}3$	4.12
3	$2.50 \times 10^{-}3$	4.10
4	$2.50 \times 10^{-}3$	3.73
5	$2.50 \times 10^{-}3$	4.12

Table 2.24: Measured Times to Travel $2.50 \times 10^{-}3$

PA - Drop 2: Freefall		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	28.39
2	2.50×10^-3	26.6
3	2.50×10^-3	28.21

Table 2.25: Measured Times to Travel 2.50×10^-3

PA - Drop 2: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	8.96
2	2.50×10^-3	8.16
5	2.50×10^-3	8.14
6	2.50×10^-3	8.32

Table 2.26: Measured Times to Travel 2.50×10^-3

PA - Drop 2: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	5.84
2	2.50×10^-3	8.54
3	2.50×10^-3	6.05

Table 2.27: Measured Times to Travel 2.50×10^-3

PA - Drop 3: Freefall		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	24.85
2	2.50×10^-3	24.73
3	2.50×10^-3	24.01
4	2.50×10^-3	33.22
5	2.50×10^-3	25.5
6	2.50×10^-3	21.08

Table 2.28: Measured Times to Travel 2.50×10^-3

PA - Drop 3: Slowrise - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	4.34
2	2.50×10^-3	4.16
3	2.50×10^-3	6.52
4	2.50×10^-3	6.33
5	2.50×10^-3	3.07
6	2.50×10^-3	3.45
7	2.50×10^-3	5.62
8	2.50×10^-3	3.60
9	2.50×10^-3	2.92

Table 2.29: Measured Times to Travel 2.50×10^-3

PA - Drop 3: Fastfall - 150 Volts		
Trial	Distance (m)	Time (s)
1	2.50×10^-3	3.40
2	2.50×10^-3	4.86
3	2.50×10^-3	4.69
4	2.50×10^-3	4.13
5	2.50×10^-3	3.06
6	2.50×10^-3	4.09
7	2.50×10^-3	2.79

Table 2.30: Measured Times to Travel 2.50×10^-3

Measured Uncertainties		
Grid Separation (m)	Voltage (V)	Time (s)
$\pm 1.45 \times 10^{-4}$	± 10	$\pm .05$

Table 2.31: Experiment Measured Uncertainties

Calculations

The calculations for determining the charge of each oil drop in the Millikan Oil Drop experiment are discussed in this lab report. The experiment involved suspending oil droplets in an electric field and measuring the forces acting on them, including the buoyant force, friction, weight, and electric force. When the droplet reached its terminal velocity, the net force acting on it became zero, which led to the calculation of the charge on the droplet. In the presence of an electric field, a charged droplet moved because of the electric force, and the rate of fall of the droplets was measured to calculate the charge on each droplet. This enabled the determination of the elementary charge of an electron. In addition, a program was written to test millions of values to determine the greatest common factor of the charges of all the recorded oil drops. The code used in this program can be found in the appendix of this lab report.

Oil Drop in Free Fall

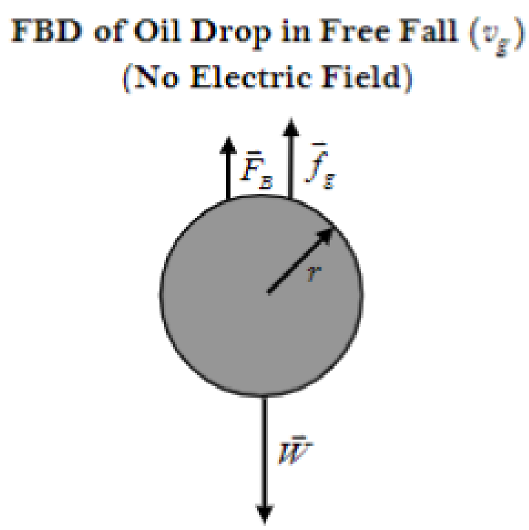

Figure 3.1: A FBD for Oil Drop in Freefall.

$$\Sigma F_b = 0 = F_b + F_g - W$$

$$r = \sqrt{\frac{9\eta V_g}{2g(\rho_{oil} - \rho_{air})}}$$

$$W = \frac{4\rho_{oil}\Pi r^3 g}{3}$$

$$F_g = 6\Pi\eta r V_g$$

Oil Drop in Slow Rise

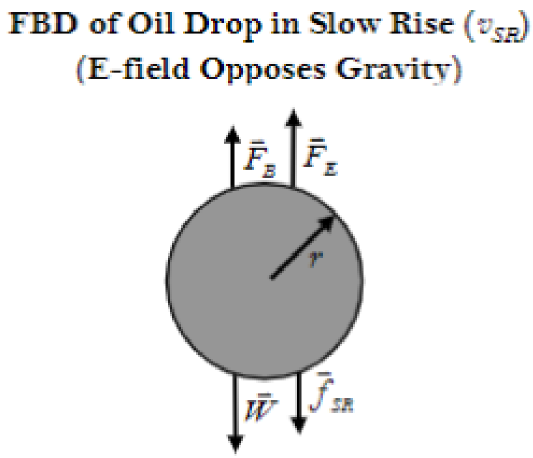

Figure 3.2: A FBD for Oil Drop in Slow Rise.

$F_b + F_E = W + F_{SR}$

$q_{SR} = \frac{K(V_g + V_{SR})\sqrt{V_g}}{V}$

$K = 1.366 * 10^{-10}(CV/(m/s^2))$

Oil Drop in Fast Fall

$q_{FF} = K((V_{FF} - V_g)(\sqrt{V_g}))/V$

Charge on Oil Drop

$q_{drop} = (q_{FF} + q_{SR})/2$

$q_{drop} = (K(V_{FF} + V_{SR})\sqrt{V_g})/(2V)$

$q_{drop_1} = ((1.366 * 10^{-10}cv/(m/s)^{3/2})(3.10 * 10^{-4}m/s + 4.92 * 10^{-5}m/s)\sqrt{1.28 * 10^{-4}m/s})/2(249.4)$

$q_{drop_1} = 1.113 * 10^{-18}C$

Results

This table shows the calculated values of velocity for all three states of the oil drops. Drops 1-7 were measured using a computer simulation, drops 8-10 were measured using a Physical Apparatus.

Averaged Velocity of Oil Drops			
Oil Drop	Free-fall Velocity (m/s)	Slow-Rise Velocity (m/s)	Fast-Fall Veloc-ity(m/s)
1	$1.28 \times 10^{-}4$	$4.92 \times 10^{-}5$	$3.10 \times 10^{-}4$
2	$3.24 \times 10^{-}5$	$4.13 \times 10^{-}4$	$4.78 \times 10^{-}4$
3	$3.23 \times 10^{-}5$	$9.04 \times 10^{-}5$	$1.56 \times 10^{-}4$
4	$3.25 \times 10^{-}5$	$2.90 \times 10^{-}5$	$9.38 \times 10^{-}5$
5	$3.24 \times 10^{-}5$	$2.90 \times 10^{-}5$	$9.38 \times 10^{-}5$
6	$3.24 \times 10^{-}5$	$9.02 \times 10^{-}5$	$1.55 \times 10^{-}4$
7	$1.29 \times 10^{-}4$	$6.97 \times 10^{-}5$	$3.23 \times 10^{-}5$
8 (PA)	$9.24 \times 10^{-}5$	$3.85 \times 10^{-}4$	$6.09 \times 10^{-}4$
9 (PA)	$9.01 \times 10^{-}5$	$2.98 \times 10^{-}4$	$3.67 \times 10^{-}4$
10 (PA)	$9.78 \times 10^{-}5$	$5.62 \times 10^{-}4$	$6.48 \times 10^{-}4$

Table 4.1: Averaged Velocities of 10 Oil Drops

Charge of Oil Drops	
Oil Drop	Charge (C)
1	$1.113\times10^{-}18$
2	$1.389\times10^{-}18$
3	$6.376\times10^{-}19$
4	$3.188\times10^{-}19$
5	$3.183\times10^{-}19$
6	$6.355\times10^{-}19$
7	$2.031\times10^{-}18$
8 (PA)	$4.34\times10^{-}18$
9 (PA)	$2.87\times10^{-}18$
10 (PA)	$5.45\times10^{-}18$

Table 4.2: Charge (q) of Oil drops

Calculated Electrons	
Oil Drop	Number of Electrons
1	6.92
2	8.63
3	3.96
4	1.98
5	1.98
6	4.00
7	12.77
8 (PA)	27.34
9 (PA)	18.03
10 (PA)	34.25

Table 4.3: Calculated Electrons using Q/e

Results	
Elementary Charge	$1.5916 * 10^{-19}C$
Percent Difference	-0.996%

Table 4.4: Percent Difference using $1.60217634{*}10^{-19}C$ for Elementary Charge

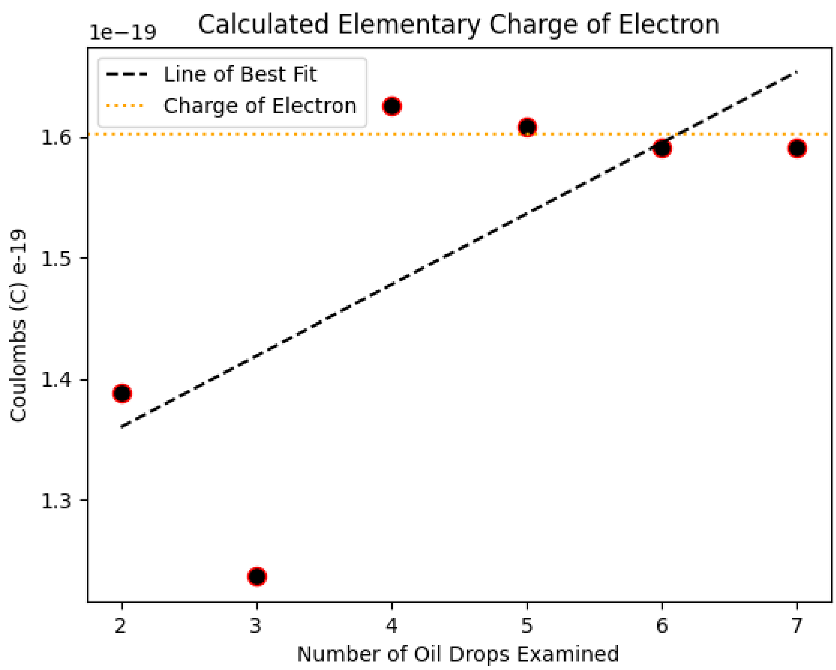

Figure 4.1: Calculated Elementary Charge of Electrons

A python script was used to examine the elementary charge of an electron, this plot demonstrates the increased accuracy of the calculated elementary charge value as the number of oil drops examined increases. After three trial drops, the calculated value for the elementary charge become within an acceptable range, and becomes closer to the accepted value for each additional drop examined. The code used can be found in the appendix of this report.

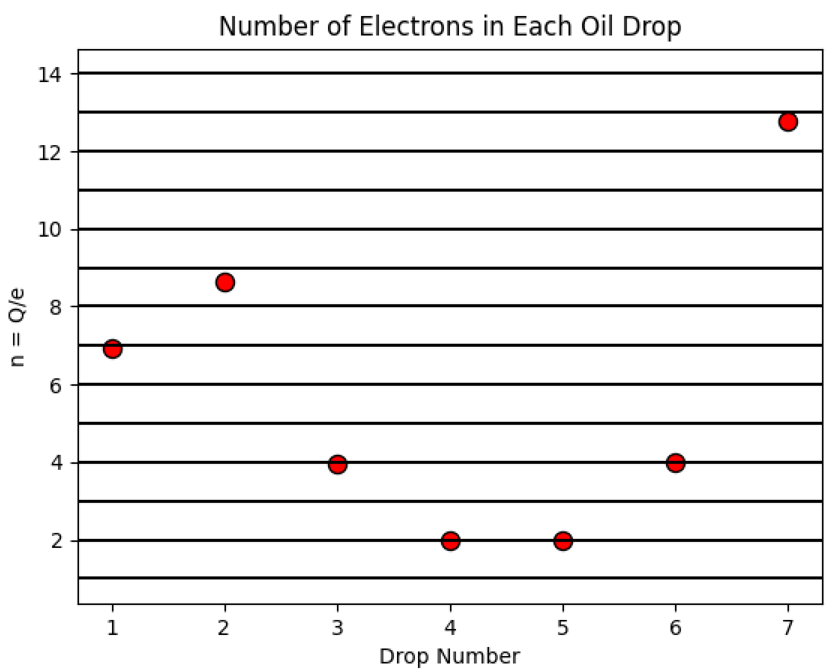

Figure 4.2: Calculated Electrons in each Oil Drop

A python script was used to plot the number of electrons calculated on each oil drop, to examine the distribution of charges in the experimental data. The code for this program can be found in the appendix of this report.

Conclusion

The purpose of this experiment was to determine the charge carried by a single electron. The data collected supports the theory that the elementary charge is 1.602×10^-19 C. The computer-generated data for the experiment had very few sources of error, as the program was designed to replicate and streamline the testing environment for the oil drops. Although this program generated accurate data that supported the initial hypothesis, it is not an experiment in the physical world and likely has assumptions based on the accepted value of the elementary charge. Therefore, the results were cross-examined with data generated from a physical oil drop apparatus.

The physical oil drop experiment was subject to several sources of error, the most significant being the presence of a third dimension for the oil drops to travel in. When suspended in the electric field, the oil drops often exhibited a velocity towards one of the walls of the oil canister, limiting the duration for which data could be accurately collected. Additionally, this movement introduced challenges to tracking the oil drops during their suspension within the canister, given their changing depth compared to the background. Despite these data collection challenges, the calculated elementary charge of an electron was not noticeably affected. In fact, with a total of three trials, the physical apparatus was found to be more accurate than the computer simulation.

The percent difference between the experimentally derived elementary charge and the accepted value is less than 1% and continued to become more accurate with each additional oil drop examined. This can be seen visually in Figure 4.1, where the calculated charge (black dots) became closer to the accepted elementary charge (orange line). With the value of the elementary charge, the number of electrons on each oil drop could be calculated by dividing the total charge by the elementary charge. All of the drops can be easily tied to an elementary charge except for drop two, which hovered between eight and nine elementary charges on board. This suggests that there was likely some error in data collection that caused this inaccurate value to be reported (see Figure 4.2).

Overall, this experiment successfully replicated the Millikan Oil Drop Experiment and supported the finding that the charge on a single electron is 1.602×10^-19 C.

Appendix

Python Code

```
import numpy as np
import matplotlib.pyplot as plt
import math

#Declarations
errors_2 = []
errors_3 = []
errors_4 = []
errors_5 = []
errors_6 = []
errors_7 = []
errors_8 = []
errors_9 = []
errors_10 = []

#The Total Electrical Charge on Oil Droplets
qDrop1 = 1.113e-18
qDrop2 = 1.389e-18
qDrop3 = 6.376e-19
qDrop4 = 3.188e-19
qDrop5 = 3.183e-19
qDrop6 = 6.355e-19
qDrop7 = 2.031e-18


#Finding Elementary Charge with 2 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
error_2 = (qDrop1 % i) + (qDrop2 % i)
errors_2.insert(q,error_2)
q = q + 1

minNumTwoDrop = (min(errors_2))
minNumIndexTwo = errors_2.index(minNumTwoDrop)
elementaryChargeTwoDrop = float("1" +"." + str(minNumIndexTwo))*10**-19
```

```
#Finding Elementary Charge with 3 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
error_3 = (qDrop1 % i) + (qDrop2 % i) + (qDrop3 % i)
errors_3.insert(q,error_3)
q = q + 1

minNumThreeDrop = (min(errors_3))
minNumIndexThree = errors_3.index(minNumThreeDrop)
elementaryChargeThreeDrop = float("1" +"." + str(minNumIndexThree))*10**-19

#Finding Elementary Charge with 4 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
error_4 = (qDrop1 % i) + (qDrop2 % i) + (qDrop3 % i) + (qDrop4 % i)
errors_4.insert(q,error_4)
q = q + 1

minNumFourDrop = (min(errors_4))
minNumIndexFour = errors_4.index(minNumFourDrop)
elementaryChargeFourDrop = float(("1" +"." + str(minNumIndexFour)))*10**-19

#Finding Elementary Charge with 5 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
error_5 = (qDrop1 % i) + (qDrop2 % i) + (qDrop3 % i) + (qDrop4 % i) + (qDrop5 % i)
errors_5.insert(q, error_5)
q = q + 1

minNumFiveDrop = (min(errors_5))
minNumIndexFive = errors_5.index(minNumFiveDrop)
elementaryChargeFiveDrop = float(("1" +"." + str(minNumIndexFive)))*10**-19

#Finding Elementary Charge with 6 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
error_6 = (qDrop1 % i) + (qDrop2 % i) + (qDrop3 % i) + (qDrop4 % i) + (qDrop5 % i) +
    (qDrop6 % i)
errors_6.insert(q, error_6)
q = q + 1

minNumSixDrop = (min(errors_6))
minNumIndexSix = errors_6.index(minNumSixDrop)
elementaryChargeSixDrop = float(("1" +"." + str(minNumIndexSix)))*10**-19

#Finding Elementary Charge with 7 Trials
q = 0
for i in np.arange(1e-19, 2e-19, 1e-23):
```

```
error_7 = (qDrop1 % i) + (qDrop2 % i) + (qDrop3 % i) + (qDrop4 % i) + (qDrop5 % i) +
    (qDrop6 % i) + (qDrop7 % i)
errors_7.insert(q, error_7)
q = q + 1

minNumSevenDrop = (min(errors_7))
minNumIndexSeven = errors_7.index(minNumSevenDrop)
elementaryChargeSevenDrop = float(("1" +"." + str(minNumIndexSeven)))*10**-19

#Plotting the Data
x_val = [2, 3, 4, 5, 6, 7]
y_val = [elementaryChargeTwoDrop, elementaryChargeThreeDrop,
    elementaryChargeFourDrop, elementaryChargeFiveDrop, elementaryChargeSixDrop,
    elementaryChargeSevenDrop]
x_val = np.array(x_val)
y_val = np.array(y_val)
a, b = np.polyfit(x_val, y_val, 1)
plt.plot(x_val,a*x_val+b, label="Line of Best Fit", color="Black",
    linestyle="dashed")
plt.scatter(x_val, y_val, edgecolors="red",color='black', s=75)
plt.axhline(1.602e-19, color='orange', xmin=0, xmax=8, linestyle="dotted",
    label="Charge of Electron")
plt.xlabel("Number of Oil Drops Examined")
plt.ylabel("Coulombs (C) e-19")
plt.title("Calculated Elementary Charge of Electron")
plt.legend()
plt.show()

#Finding the Number of Charges in Each Oil Drop
NumChargeDrop1 = qDrop1 / elementaryChargeFiveDrop
NumChargeDrop2 = qDrop2 / elementaryChargeFiveDrop
NumChargeDrop3 = qDrop3 / elementaryChargeFiveDrop
NumChargeDrop4 = qDrop4 / elementaryChargeFiveDrop
NumChargeDrop5 = qDrop5 / elementaryChargeFiveDrop
NumChargeDrop6 = qDrop6 / elementaryChargeSixDrop
NumChargeDrop7 = qDrop7 / elementaryChargeSevenDrop

#Plotting Number of Charges on Each Oil Drop
x_val_1 = [1, 2, 3, 4, 5, 6, 7]
y_val_1 = [NumChargeDrop1, NumChargeDrop2, NumChargeDrop3, NumChargeDrop4,
    NumChargeDrop5, NumChargeDrop6, NumChargeDrop7]
x_val_1 = np.array(x_val_1)
y_val_1 = np.array(y_val_1)
a, b = np.polyfit(x_val_1, y_val_1, 1)
plt.scatter(x_val_1, y_val_1, edgecolors="black",color='red', s=75)
plt.xlabel("Drop Number")
plt.ylabel("n = Q/e")
plt.title("Number of Electrons in Each Oil Drop")
plt.show()
```