Robert Millikan (top center) on the steps of Ryerson Laboratory, U. of Chicago, 1908. Other colleagues (L-R): A. A. Michelson, Carl Kinsey, Henry G. Gale

ROBERT A. MILLIKAN
Oil Drop Experiment Notebooks

NOTEBOOK ONE:
October 1911-March 1912

PART 2 OF 3
From page 40 to page 79

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Abstract

Robert A. Millikan (1868-1953) began his experiments to measure the charge on the electron, e, in 1907. The experiments were performed in Ryerson Laboratory at the University of Chicago, where Millikan was professor of physics. For this work, and for work on the photoelectric effect, Millikan was awarded the Nobel Prize in physics in 1923.

Millikan gives his own account of the electron charge determination in his published autobiography in the chapter titled "My Oil-Drop Venture (e)" (Robert A. Millikan, *The Autobiography of Robert A. Millikan*, New York, 1950). With the aid of graduate students Louis Begeman, Harvey Fletcher, and J. Y. Lee, Millikan devised the method of measuring the rate of fall of a single electrically charged oil drop under the forces of gravity and electricity. From 1909 until the spring of 1912, Millikan reports, he spent every available moment in the laboratory on his oil-drop experiment. His first comprehensive, though to some extent preliminary, results were published in September 1910 in the journal *Science* as "The Isolation of an Ion, a Precision Measurement of Its Charge, and the Correction of Stokes' Law," *Science* 32: 436-448. He soon became embroiled in a controversy with the Viennese physicist Felix Ehrenhaft, who claimed to have found much smaller electric charges. Millikan went back to work on a new

set of experiments. By the spring of 1912 he had collected the data for what he termed "the final, absolute determination of the numerical value of the electron" (*Autobiography*, p. 84). Results were published in August 1913 in "On the Elementary Electrical Charge and the Avogadro Constant," *Physical Review* 2: 109-43. This last, definitive set of experiments were recorded in the only two lab notebooks which Millikan preserved among his papers. These two notebooks are presented here in facsimile. They cover the period from October 1911 through April 1912 and contain what Millikan himself considered his conclusive, historic work on this problem.

For an analysis of Millikan's notebooks and a defense of his experimental method, see the article by David Goodstein, "In Defense of Robert Andrews Millikan," published in *American Scientist* 89/1 (Jan-Feb. 2001): 54. http://www.americanscientist.org/issues/num2/2001/1/in-defense-of-robert-andrews-millikan/1

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2nd Obs^t at (mag. 1022)

Blue drop.

4:35 P.M.

$t = 22.8°$

96.12
17.40
$p =$ 78.72

t_g	F
47.3	~~15.3~~
47.2	22.052
47.1	29.750
47.0	14.652
6	
47.15	

4:50

~~[illegible]~~
14.652
~~[illegible]~~
14.652
22.052
29.750

Volts at 4:55
846 + 13.0
830 + 14.1
834 + 13.6
858 + 12.8
836 + 13.6
841 + 13.2
5045 + 80.3
50
5125

5165
5125
43 = drop

$v_1 = \frac{1022}{47.15} = .01472$

.00945
.673482
2 – .338968 – 2
.167984 – 1

$v_2' = \frac{1022}{14.652} =$ [illegible]

.00945
1.18[illegible]
.8[illegible]
→
.06976
.01472
.08448

$v_2'' = \frac{1022}{22.052} = .04635$
.01472
.06107

.00945
1.343408
.66600 – 2

$v_2''' = \frac{1022}{29.750} = .03435$
.01472
.04907

.00945
.473487
.532963 – 2

$v_1 + v_2 = .08448 \div 7 = .01207$
$= .06107 \div 5 = .01221$
$= .04907 \div 4 = .01227$
55
.01218

.085647 – 2
167984 – 1
198300 – 3
.451931 – 6
709694
.742237

55² (?)

3rd obs. at
5:05 P.M.

$l = 23.0$

$p = 96.30 - 17.30 = 79.00$

G	F
50.4	16.0
50.8	26.1
50.4	20.0
50.9	16.310
	26.116
50.1	20.392

5:20

4th obs. at
5:30 P.M.

94.92 − 18.61 = 76.31

t = 23°

G	F
~~17.9~~	
~~17.9~~	9.786
~~18.1~~	7.364 } 7.594
18.378	7.824
	35.6
	36.250 — (?)
18.370	35.214
? 19.098	24.340
? 19.170	28.466 — 35.610
18.506	35.650
18.556	35.906
18.554	
18.606	
18.420	57.202
18.612	18.0 at half
18.758	35.9 whole dist.
18.408	
12)223.430	
18.620 18.105	

7.594
9.786
24.340
28.466 — (?)
35.610
36.250 — (?)
57.202

Volts at 6:10 P.M.

830 + 14.1
828 + 12.7
826 + 14.5
855 + 12.8
829 + 14.1
850 + 12.9
5018 + 80.6
80
5098

5125
5098
27 = drop.

$v_1 = \frac{1022}{18.62} = .06910$ .009451 / 1.364926 / 2.839481-2 / .419785-1 / .009451 / .880471 / .158980-1

$v_2 = \frac{1022}{7.594} = .13458$ / .06910 / .20368

$\frac{1022}{9.786} = .10448$ / .06910 / .17358 — .009451 / .990428 / .019023-1

$\frac{1022}{24.34} = .04199$ / .06910 / .11109 — .009451 / 1.356321 / .623130-2

$\frac{1022}{35.61} = .02870$ / .06910 / .09780 — .009451 / 1.551572 / .457879-2

$\frac{1022}{57.202} = .01787$ / .06910 / .08697 — .009451 / .757346 / .252055-2

.20368 ÷ 19 = .01072
.17358 ÷ 16 = .01085
.11109 ÷ 11 = .01009 — ?
.09780 ÷ 9 = .01086
.08697 ÷ 8 = .01086

.01082

Friday, Jan. 26, 1912   t = 23.   P = 9415 − 1925 = 749

Volts at 3:15 P.M.

1 − 847 + 13.0 = 860.0
2 − 850 + 12.9 = 862.9
3 − 831 + 14.0 = 845.0
4 − 857 + 12.8 = 869.8
5 − 837 + 13.5 = 850.5
6 − 852 + 129 = 864.9

5074 + 791 = 5153.1
791
5153.1

Positive drops

5153
5138
41
5146

Obs. at 3:23

G.	F	G. (cont)	F (cont)
9.642		9.670	24.0
9.630			24.4 (?)
? (9.570)		9.670	24.2
9.662			28.6 } ½
9.666			57.0 }
9.648	7.430	9.620	
	7.436		28.0 } ½
9.608		9.658	56.4 }
	55.8		28.4 } ½
	17.3		56.4 }
9.668	17.8	9.7	
? (9.532)	17.4	Finished at 3:55	
	17.6		
	17.4	mean 9651	
9.662	17.2		7.433
	17.6		17.500
	17.6		23.950
9.674	17.6		56.400
	77.0		77.000
9.632	23.7		
9.658	24.0		
9.7	24.0		
9.7	23.8		
9.7	21.2		
9.6	21.4		

$v_1 = \frac{.00445}{.48457}$ 2 | .039857 / .51244-1 $\frac{1022}{9.651} = .1069$

$\frac{.00445}{.57.116}$ .10329-1 $\frac{1022}{7.433} = .13750$ .10690 / .24440 ÷ 49 = .004965

$\frac{.00445}{1.24304}$ .76541-2 $\frac{1022}{17.500} = .05840$ .10690 / .16430 ÷ 33 = .004950

.00445 / 1.37970 / .62994-2 $\frac{1022}{23.950} = .04263$ .10690 / .14853 ÷ 30 = .004951

.00445 / 1.75135 / .25317-2 $\frac{1022}{56.400} = .01812$ .10690 / .12402 ÷ 25 = .004961

.00445 / 1.88649 / .12294-2 $\frac{1022}{77.000} = .01329$ .10690 / .12019 ÷ 24 = .004965

297
.004958

51244
69531
~~56914~~
19830
~~46275~~
~~41147~~
~~95128~~
.40605
71147
.69458

E = .4950

2nd Obs. t = 23.3 P 94.10 − 19.40 = 74.70

Blue drop − Positive dep.

Volts at 4:10

1 − 844 + 13.0 = 857.0
2 − 848 + 12.9 = 860.9
3 − 827 + 14.3 = 841.3
4 − 855 + 12.8 = 867.8
5 − 836 + 13.5 = 849.5
6 − 849 + 12.9 = 861.9
5059 79.4 5138.4
79.4
5138.4

00945
1.72754
2.28191 − 2
.14096 − 1

1022 / 53.4 = .01914

V = 5134
log V =

00945
1.74194
.2575 − 2

1022 / 55.2 = .01852
.01914
.03766 ÷ 3 = .01255

B.	F		
Began at 4:15 P.M.			
	88.6 } ÷ ½		
27.0 } ÷ ½	172.8 }		
53.4 }			
	28.0 } ÷ ½		
26.6 } ÷ ½	55.2 }		
53.4 }			
Finished at 4:27			

.00945
2.23754
.97191

1022 / 172.8

.005915
.05915
.01914
.07829 ÷ 6 = .01304
.025055

.02587
.01293
.01253

mean = .01254

.0983
.14095
.1963
.4376
.7104
.7272

.11160 − 2
.14095 − 1
.19830
.45085
.71046
.74039

E = ~~5.500~~ 5.336 Correct = 5.452 × 10⁻¹⁰
5.492

2.1% low

3rd Obs Jan. 26, 1912 t = 23. P = 74.80

volts at 4:30
1 - 843 + 13.1 = 856.1
2 - 847 + 13.0 = 860.0
3 - 825 + 14.5 = 839.5
4 - 854 + 12.8 = 866.8
5 - 834 + 13.5 = 847.5
6 - 848 + 12.9 = 860.9
5130.8

Blue drop - positive,
Very much like the one taken
at the 2nd Obs.

B.	F	
35.9 71.8 Red drop.		00945 171550 .39345-2 .14196-1 $\frac{1022}{51.94}$ = .01968
Obs. began at	19.0	00945 127875 .930702 $\frac{1022}{19.00}$ = .05379 .01968 .03411 ÷ 6 = .01225
26.0) ÷ ½ 52.0)	35.0 ~~50.0~~	00945 1022 154407 36.00 .48538-2 = .02920 .01968 .00888 ÷ 4 = .01222
26.0) ÷ ½ 51.8)	60.7 ~~57.0~~	00945 178319 .22626-2 $\frac{1022}{60.70}$ = .01684 .01968 .03652 ÷ 3 = .01218
26.37 ÷ ½ 52.0)		.01222
52.3		
52.0		
mean 51.94		.0871 .1470 1463 4324 7101 7223 .08707 .14196 .19830 .42733 .71012 .71721 e = 5.215
5)25977 5194		5.276

3½ % low

probably a double drop

4th Observation at 5:10   t = 23.1   P = 74.80

Was not taken immediately after blowing.
May be a dust particle

.009451 1.022/166.57 .007823 .006135   5130 5111 41 5120

.221597
2) .787854-2
.893927-2

G	F
83.4 } = ½ 167.0	24.4 } = ½ 57.8
84.2 } = ½ 167.2	29.0 } = ½ 57.4
84.0 } = ½ 167.4	24.4
84.6 } = ½ 166.2	24.7
82.0 165.0	29.4 } = ½ 58.4
5) 16-32.8 166.56	

Finished at 5:37

.009451 1.390051 .6194002   1.022/24.55 = .04163 .007823 .049453 ÷ 2 = .024733 .02388 6135 4777

.009451 1.762378 .247078-2   1.022/57.86 = .017667 .007833 .025500 2360   2380.

.024733 .025500 2) .050233 .025116   ... 1.02384

24.4 24.7 11 24.55

57.8 57.4 58.4 3) 173.6 57.86

.399999-2 .893927-2 .148300-3 .493176 .709270 .801446 .782906

$\varepsilon = 6.066$

.3773 8934 1983 4695 7093 .7602

5757 / 3

5.760   Const = 5.71

1% high Error 1%

5th Obs. – Jan 26, 1912   t = 23.5   P: 74.80

Volts at 5:38   White drop –

1 – 839 + 13.2 = 852.2
2 – 842 + 13.1 = 855.1
3 – 818 + 14.9 = 832.9
4 – 853 + 12.8 = 865.8
5 – 832 + 13.9 = 845.9
6 – 846 + 13.5 = 859.5

5111.4

5:45 P.M.

G	F	
43.4		
21.6 } 43.0 }	25.3 } 49.4 }	
43.6		
433		

Finished at 6:00

.009451
1.636485
2 | .373963 – 2
.186481 – 1

1022 / 43.3 = .02360

1022 / 49.4 = .02069

.009451
1.693727
.315724 – 2

.02069
.02360
4 | .04429
.01107

.033943

.031087

.915621

.044048
.186481
1953
.428829
.705421
.920608

E = 5.254
17
5.270

Corrd 5.305

.7% low error 1%
but probable ~~~ of the
1% is to reduce the
value of e still
lower

.2033
2360
43.86
1097

6th (1/26/12) 6-P.M. t = 23.2 P = 74.75

Perhaps Reddish drop

Volts at 6:18 P.M.

Obs. began at 6:05

b	F
71.2	17.6 } = 1/2 35.2 }
35.0 } = 1/2 71.0 }	11.9 } 23.8 }
35.6 } = 1/2 71.4 }	36.0 } = 1/2 71.0 }
71.6	balanced
71.3	

1 - 838 + 13.3 = 851.3
2 - 843 + 13.1 = 856.1
3 - 817 + 15.0 = 832.0
4 - 853 + 12.8 = 865.8
5 - 830 + 14.1 = 844.1
6 - 844 + 13.0 = 857.0

5106.3

.009451
1.853090
1.156361-2
.0781804-1

1022 / 71.3 = .01423

.009451
1.376577
.632874-2

1022 / 23.8 = .04294
.01423
.05717 ÷ 4 = .01429
= .01432

.009451
1.546543
.462908-2

1022 / 35.2 = .02904
.01423
.04327 ÷ 3 = .01442
01446

.009451
1.851255
.158193-2

1022 / 71.0 = .01439
.01433
.02872 ÷ 2 = .01436
1 07
.01439

.158061-2
.078150
1983
.434541
708081
.726460

5.256
5
E = 5.261
5.331

2% low

Error .5%

t_g t_F n

71.2 35.2 3 .01436
71.0 23.8 2 .01399
71.4 71.0 .01408
71.6

71.3

$\frac{1}{71.3}$ = .01403

$\frac{1}{35.2}$ = .02841

$\frac{1}{23.8}$ = .04202

$\frac{1}{71}$ = 1408

1403
1541

Saturday, Jan 27th 1912

Volts at 10:30 a.m. t = 23.0

P. = 94.45 − 18.95 = 75.50

1 − 830 + 14.1
2 − 830 + 14.1
3 − 758 + 18.0
4 − 840 + 13.2
5 − 815 + 15.2
6 − 832 + 14.1
4905 + 88.7 = 4993.7

G.	F
11.756	
11.654	
11.934	
11.578	
11.934	
11.792	7.424
11.810?	49.
	24.6 } = ½ ; 49.4 }
	42.0 } = 5/8 66.7 ; 66.7 }
	33.9 } = ½ ; 66.6 }
11.740	16.6 } = ½ ; 32.5 }
11.478	16.3 } = ½ ; 32.4 }
11.686	32.5
10) 117.569	
11.756	

324
325
335
32.46
49.20
66.65

.009451
.070262
.088189

.009451
1.070262
2 | .999193 − 2
.474596 − 1

.009451
1.511349
.498102 − 2

.009451
1.691915
.317486 − 2

.009451
.873800
.135651 − 2

1022 / 11.756 = .08694 (.08673)

1022 / 32.46 = .03148 ÷ 6 = .005236
.08694 ÷ 24 = .005018
.12044 ÷ 22 = .005475 5363
11842

1022 / 49.20 = .02077 ÷ 21 = .005351
.08694 ÷ 22 = .004984
.10771 ÷ 20 = .005487
10771

1022 / 66.65 = .01533 (20 = .005214)
.08694 ÷ 21 = .004966 5366
.10227 ÷ 19 = .005489 5383
10227

mean = .005384

.03148
.08673
.11821

5475
5487
5489
231
.005480

105477

.739572 − 3
.474596 − 1
.1983
.414468
.698449
.714019

4311
4696
1983
3990
6984
7006

e = 5.176
error

e_1 = 5.002 correct

2% low

error low .8%

2nd Obs. 1/28/12 t = 23 P = 75.50

g	F
13.6 } = ½ —	25.6 } = ½ 49.6
13.6 } = ½ 27.0	49.0
13.3 } = ½ 26.6	~~[illegible]~~
13.6 } = ½ 26.8	
26.8	
13.4 } = ½ 26.6	42.6 } = ½ 83.0
13.6 } 27.2	18.0 } = ½ 35.2
13.9 } 27.3	~~[illegible]~~

11:45

35.2
49.3
83.0

27
26.6
26.8
26.8
26.6
27.2
27.3
7 | 188.3
26.9

11:20

Volt at. 11:10

1 - 830 + 14.1 = 844.1
2 - 829 + 14.1 = 843.1
3 - 746 + 18.0 = 764.0
4 - 839 + 13.2 = 852.2
5 - 814 + 15.2 = 829.2
6 - 832 + 14.1 = 846.1
4978.7

.009451
1.429752
2.579609 - 2
.289849 - 1

1022 / 26.9 = .03799

.009451
1.546542
.462909 - 2

1022 / 35.2 = .02838 (2904)
.03799
.06637 ÷ 8 = .00829
06694 = .008368

.009451
1.692847
.316604 - 2

1022 / 49.3 = .02073
.03799
.05872 ÷ 7 = .008389

.009451
1.919078
.090373 - 2

1022 / 83.0 = .01231
.03799
.05030 ÷ 6 = .008383
3 | 106
.00835
.008380

.921686 - 3
289849
1983
.480438
697055
.712780

7114
6971
7143

ε = 5.162 5.180 5.217 correct

.75% low stop watch gs possible error 1%

3rd Obs. 1/23/12 t = 23.

1 - 829 + 14.1 = 843.1
2 - 829. + 14.1 = 843.1
3 - 740 + 18.0 = 758.0
4 - 838 + 13.2 = 851.2
5 - 813 + 15.2 = 828.2
6 - 831 + 14.1 = 843.1

4968.7

Volts at 11:50

~~Test for Conv~~

temp = 23.2 °C.
pres = 75.9

12:15

F

within 4 small divs. from bottom to within 7 small div. of top

24.6 = 1st 2 large division
25.6 = 2nd 2 large divs
25.6 = 3rd 2 divs
25.4 = 4th 2 "
25.6 = 5th " "
24.0 = 6th " "

from 5 small from bottom to within one div. of top

21.3 = 1st large 2 divs
20.1 = 2nd "
21.6 = 3rd "
21.9 = 4th "
21.4 = 5th "
21.6 = 6th "
22.0 = 7th "
21.2 = 8th "
21.0 = 9th "
21.0 = 10 "
20.6 = 11 "

(12:40)

This seems to show clearly that the field is not exactly uniform being stronger at the edges than in the middle

TEST FOR CONVECTION

t = 23.0 °C
p = 75.60

(12:45)

F

within 5 small div. of bottom to within 1 large div

15.4 = 1st 2 large divs. — 2nd reading = 15.0
16.0 = 2nd 2 " — = 16.0
16.0 = 3rd 2 "
16.0 = 4th 2 " — " 15.6 = 2nd read. 15.9
15.4 = 5th 2 "
15.6 = 6th 2 "
15.6 = 7th 2 "

too many divisions here, toward the middle there must be a deflection

within 5 small divs. of bottom to within 2 div. of plate

15.6 = 1st 2 l. divs.
16.2 = 2nd "
15.9 = 3rd "
16.0 = 4th "
15.6 = 5th "
15.6 = 6th "

which overlaps 5 small into 6th 2 large divs. } = 15.6 2nd reading

within 5 small divs. of bottom to within 2 small divisions of plate

118.9 = 1st div	122.5 = 1st div	
121.0 = 2nd	125.5 = 2nd	
131.6 = 3rd	135.0 = 3rd	
145.2 = 4th	147.0 = 4th	
140.0 = 5	152.4 = 5	
141.0 = 6th	151.6 = 6	
137.8 = 7th	146.2 = 7	
133.4 = 8th	141.6 = 8	
131.0 = 9th	147.2 = 9	
119.0 = 10th		
113.0 = 11th		
110.0 = 12		

2nd readings after all of 1st to left were taken and these show that voltage was dropping.

2:05 P.M.

same drop as used for testing for connection on last page.

from 2:05 P.M.

$t = 23.2°C.$

$p =$

Volts at 2:25 P.M.

	G	F	
on middle of field	11.4	1st half of 8 divs	60.0 for 1st half
	22.8	2nd " " 8 "	120.6 " 2nd "
	22.810	for all 8 divs	121.0 " all 8 divs.
	22.900	" " "	
	22.990	" " "	32.0 = 1st half of 8 divs
	22.998	" " "	63.7 = 2nd " " " "
	22.974		63.3 = all 8 divs.

to 2:25 P.M.

(1) 8274 14.3
(2) 8237 14.6
(3) 7227 18.8
(4) 8838 13.4
(5) 8137 15.3
(6) 8274 14.3

4860 89.9
90
4940

$V_1 = \frac{1022}{22.96} = .04450$

.04941
3010
.64645

$V_2 = \frac{1022}{63.5} = .01609$

.06059

$\log 1.10_0 = 2.7824$
$n \log v_1 = 1.3242$
$.3.1983$
5.3049
3.6937
-9.6112
$8) 4085$
5.106_5
$e_1 = 5.111$

1.8% low

error .6%

Friday ~~Jan~~ Feb. 2, 1912. $t = 23.1$ $P = 74.92$

Test for Convection.

Volts at 3:25

1 – 851 + 12.9 = 863.9
2 – 850 + 12.9 = 862.9
3 – 822 + 14.7 = 836.7
4 – 859 + 12.8 = 871.8
5 – 833 + 13.5 = 846.5
6 – 847 + 13.0 = 860.0
5062 + 79.8 = 5141.8

G

22.6 1st 2 div
45.6 2nd 2 div.
22.6 3rd 2 div.
45.2 4th 2 div
22.4 5th
38.8 1/5

22.6 –
23.0 –
22.6 –
22.6 –
22.4 –
24.6 – Snow within 3 small div of the bottom.

2nd Obs. - 4:00 P.M. $t = 23$ $p = \frac{94\frac{7}{10}}{74.95}$

Red drops.

$\frac{102.6}{53.2}$
$\frac{49.2}{}$

136
264

G	F
53.4 - 1st div.	13.6 - 1st 4 div.
49.2 - 2nd div. 1.4 p.d.	26.8 - 1st + 2nd 4 div.
50.2 - 3rd div.	
54.4 - 4th div.	
52.4 - 5th "	
47.6 - 6th "	
48.0 - 7th "	
52.2 - 8th "	
48.4 - 9th "	

3rd Obs. - at. 4:50 P.M. t = 22.9 p = 74.95

Volts at 4:40

1- 849 + 12.9 =
2- 848 + 12.9 =
3- 814 + 15.3 =
4- 857 + 12.8 =
5- 831 + 14.1 =
6- 843 + 13.1 =

5042 + 81.1 = 5123.1

.00 9451
88110
.12833 - 1
.00445
1.08445
1.31345
.69600 - 2

.00945
1.37620
.61325 - 2

.00945
1.51055
.49890 - 2

.00945
1.74468
.26477 - 2

.00945
2.97313
.03632 - 3

$\frac{1022}{7.605}$ = .13442

$\frac{10.22}{20.58}$ = .04966
.13442
.18408 ÷ 42 = .004383

$\frac{1022}{24.9}$ = .04104
.13442
.17546 ÷ 40 = .004386

$\frac{1022}{32.4}$ = .03154
.13442
.16598 ÷ 38 = .004367

$\frac{1022}{55.55}$ = .01840
.13442
.15282 ÷ 35 = .004366

$\frac{1022}{940.0}$ = .001087
.134420
.135507 ÷ 31 = .004371
204
.004368

Stop watch G	Chron	F 15½	whole
	7.558		
7.4	7.566		
7.5	7.532		
7.6	7.786		20.58
7.8	7.440		6) 35
7.4	7.658	10.6	20.5
7.6	7.660	10.6	20.8
7.4	7.596	10.6	20.6
7.6	7.418	10.3	20.6
7.8		10.2	20.4
7.4	7.716	—	20.6
55			
7.55	7.608	12.6	24.9
	7.580	12.5	24.9
		1st div = 113.0 2nd " = 111.6 3rd " = 123.0 4th " = 119.0 5th " = 120.0 6th " = 118.6	
	7.644		
		—	32.2
	7.700	—	32.6
	7.676	—	55.7
	7.550	27.0	55.4
		35.0	
	16) 7.678		
	7.605		

24.9

117.5
8
940.0

32.4

55.55

64028 - 3
56417 - 1
19830 - 2
×40275 - 6
log .5115 = 70885 - 3
6.9390 - 10

4.942 Corr't 5051

219, Rev

5123.1
5111

15406
17546
21,00862
431

17546
13558
9)03988
444
431
435
439

16598
13558
7)03047
435

16598
15282
3)01316
439

4)1848 (45
164
208

1748
4372

4th Observation at 5.35 $t =$ $p =$

Volts at 5.26

1 - 848 + 12.9 = 860.9
2 - 844 + 13.0 = 857.0
3 - 813 + 15.4 = 828.4
4 - 854 + 12.8 = 866.8
5 - 829 + 14.1 = 843.1
6 - 842 + 13.1 = 855.1

5030 + 81.1 = 5111.1

G	F	
	1/2	whole

Saturday - Feb. 3rd 1912 $t = 21.8$. $P = \frac{94.15}{74.85}$

Volts at 10:25 A.M.

1 -	837 + 13.4 =	850.4
	833 + 13.9 =	846.9
	780 + 17.0 =	797.0
	847 + 13.0 =	860.0
	813 + 15.4 =	828.4
	830 + 14.1 =	844.1
	4940 + 86.8 =	5026.8

Note: Take value of volts on next page -

.00945		1022 / 48.675 =	.02100
1.68730			
2 .32215-2			
.16108-1			
.00945		1022 / 11.3 =	.09044
1.05308			.02100
.95637-2			.11144 ÷ 10 = .01144
.00945		1022 / 17.25 =	.05925
1.23679			.02100
.77266-2			.08025 ÷ 7 = .01146
.00945		1022 / 77.0 =	.01327
1.88645			.02100
.12800-2			.03427 ÷ 3 = .01142

.01144

G		F	
½ Distance	Whole Dist	½ Distance	Whole Dist
—	48.6	38.6	77.0
24.4	48.7	8.7	17.3
24.3	48.6	—	11.3
24.4	48.8	—	17.2
	4 | 2.7		
	48.675		

.05843
.16108
1.98430
.41781
.69627
.72154

5.267
28
5.239

5,340 Cms

2% low

2nd Obs. at 11:05 A.M.
t = 22 p = 74.95

½	whole	½	whole
G		F	
56.0	109.0	20.0	40.4
—	107.6	20.0	40.2
52.6	107.6	20.6	40.6
52.4	107.0	—	24.2
53.4	108.0	66.6	133.6
52.4	106.6	20.0	40.2
56.6	107.8		
	7) 55.6		
	107.9		

Volts at 10.155

1 - 836 + 13.5 = 849.5
2 - 832 + 13.9 = 845.9
3 - 726 + 18.0 = 744.0
4 - 846 + 13.0 = 859.0
5 - 812 + 155 = 827.5
6 - 829 + 14.1 = 843.1

4881 + 98.0 = 4969.0
88
4969

.00945
2.03302
2.97643-3
.988 21-2

1022 / 107.9 = .009472 ✓

.00945
1.38382
.62563-2

54.20
40.35
133.60

1022 / 54.20 = .04223
.00947
.05170 ÷ 3 = .01723 ✓

.00945
1.60584
.40361-2

1022 / 40.35 = .02533
.00947
.03480 ÷ 2 = .01740 ✓

.00945
2.12581
.88364-3

1022 / 133.60 = .007650
.009472
.017122 ÷ 1 = .01712 ✓

3 | .017175
.01725

.23679-2
.98821-2
.19830-3
.42330
69627
.72703

5.335
24
5.311

49. low

3rd Obs – 11:48 AM.

t = 21.9 p = 74.95

Volts at 12:

G		F	
~~79.7~~	~~= 1st div.~~		
~~82.4~~	~~= 2nd "~~		
~~102.0~~	~~= 3rd "~~		
~~95.6~~	~~= 4th " (2400)~~		
57.0	1st div.	13.3	26.4
57.9	2nd div.	—	26.5
60.6	3rd div.		5
128.0	4th + 5th div.		
135.6	6th + 7th div.		
59.4	8th div.		
60.0	6th div.		
120.6	6th + 7th		
59.0	8th div.		
58.4	1st div.		
48.6	2nd div.		
56.6	3rd div.		
60.0	4th div.		
62.3	5th div.		
62.9	6th div.		
61.4	7th div.		
	8th div.		

~~4)240.2~~

58.6

mean fall (12:30)

60.3 × 8

= 482.4

1 – 834 + 13.5 = 847.5
2 – 830 + 14.1 = 844.1
3 – 720 + 18.0 = 738.0
4 – 844 + 13.0 = 857.0
5 – 808 + 15.6 = 823.6
6 – 825 + 14.5 = 839.5

= 4949.7

.00945
6934
32425

$V_1 = \frac{1.022}{468.8} = .002188$

.00945
1.4224
–3.58105

$V_2 = \frac{1.022}{26.45}$ .03864

$V_1 + V_2 = .04082$

Log $V_1 + V_2$ = –2.6109
$\frac{1}{2}$ " V_1 = –2.6680
–3.1983
–6.9722
–3.6946
–10.7776

5.993
25
e_1 = 5.968

Good one fairly small one

Perm 59, low (a guess have not worked out)

4th Obs. — at 12.45 t = 22 p = 74.80

Volts at 1:131

1 - 833 + 13.8 = 846.8
2 - 829 + 14.1 = 843.1
3 - 715 + 18.0 = 733.0
4 - 843 + 13.1 = 856.1
5 - 803 + 15.8 = 818.8
6 - 822 + 14.7 = 836.7

4934.5

Stopwatch - Chronograph	½	whole
G	F	
7.100	25.6	50.3
7.058	24.7	49.8
7.028		
7.184	31.9	63.2
7.174	31.6	63.4
7.154	31.7	63.3
7.090	11.3	22.4
7.154	14.4	—
7.216		22.6
7.078	11.6	
7.182	11.6	23.0
7.158		
7.120		
7.142		
7.088		
7.136		14.7
7.086		
7.094		14.8
(18) 2.242		26.4
7.125		66.6
	33.4	66.6
		16.8
		17.0
	12.6	25.6
	12.9	25.4

(1:10 PM)

.00845
.8578
-1.15666

$v_1 = \frac{1022}{7.125} = .14344$

$v_1' = \frac{1022}{50.05} = .02042$ / 14344 = .16386 ÷ 39 = .0042015

Differences

.242413 - .158785 = [8] .045188 / .004102

.18352 - .158785 = [6] .024735 / .004125

.18552 - .15959 = [7] .02893 / .004133

.17843 - .158785 = [5] .020675 / .004129

.21343 - .15878 = [13] .54145 / .004165

$\frac{1022}{63.3}$ .016185 / 14344 = .15959 ÷ 38 = .004200; 00427

$\frac{1022}{22.67}$ = .04508 / 14344 = .18852 ÷ 45 = .0041893

$\frac{1022}{14.75}$ = .069 / 14344 = .21243

$\frac{1022}{28.4}$ = .035986 / 14344 = .17943

$\frac{1022}{66.6}$ .015345 / 14344 = .158785 ÷ 38 = .004177

$\frac{1022}{16.9}$ .06093 / 14344 = .20393 ÷ 49 = .004615

$\frac{1022}{25.5}$ .04008 / 14344 = .18352 ÷ 44 = .004171

42015
42000
41893
4177
4161.5
4171
[6] 1.1003
4183

4102
4125
4133
4129
4165
[5] 154
4131

Log $v_1 + v_2$ = 3.6215
$\frac{3}{2}$ log v_1 = -4.5783
-3.1463
-6.3981
3.6932
-10.7049

e = 5069
23
e = .5046 equal weight

4096 | These first better
4091 | than last two
4099 | max diff being .6%
4092 | against 1%. and
4078 | they [illegible] differences
4078 | better [illegible]
6) 4086 | [illegible]

[illegible] log [illegible] = 3.6113
-1.5763
3.1982
6.3879
3.6922
10.6947

4.951
22
4.929

Error 7%

[illegible] %, [illegible]

Friday. Feb. 9th 1912 $t = 23$

94.4 − 19.15
$p = 75.25$

A Blue drop-

13 Blue - positive drops
Observed at 10:30 A.M.

Volts at 10:15
1 - 836 + 13.5 = 849.5
2 - 833 + 13.8 = 846.8
3 - 779 + 17.0 = 796.0
4 - 846 + 13.0 = 859.0
5 - 818 + 16.0 = 833.0
6 - 833 + 13.8 = 846.8
4945 + 86.1 = 5031.1
5031.1

G		F	
½ div.	whole D		
—	57.6		
27.6	57.6		
27.7	58.4		
28.6	58.1		
28.0	58.2		
—	58.6	82.0	172.0
29.0	58.6	82.0	174.8
28.4	—	29.6	59.2
28.0	56.6		

Increase on accf
Correction as shown on next page.

2nd Observation at. t= p=

Volts at 11:00 A.M.

1 - 835 + 13.6 = 848.6
2 - 832 + 13.9 = 845.9
3 - 781 + 17.0 = 798.0
4 - 845 + 13.0 = 858.0
5 - 817 + 15.0 = 832.0
6 - 832 + 13.9 = 845.9

494 2 + 86.4 + 5028.4
8 6.4
5028.4

G		F	
½ dist.	whole R	½ dist	whole dist.
Middle.			
30 2 divs			~~326 divs~~
33 "			
34.8 "			
~~31~~ "			~~64~~ "
~~35~~ "			
34.9			~~1324~~
882 2 divs		426	2 divs
		894	4 divs
83.42 divs			2924 divs
97.82 divs			954 "

94.6-18.85

3rd Observation – at 3:35 P.M. t=23.0 p=75.75

Volts at 3:35 P.M.

1.- 834 + 13.7 = 847.7 } Only one battery was used

2.- 8 +1 =

3.- 8 +1 =

4.- 8 +1 =

5.- 8 +1 =

6.- 8 +1 =

G	F	
	½ dist	whole
21.4 - 2 div		
21.4 2 div		
22.6 - 2 div		
21.7 - 2 div	15.6	31.0
87.1		
21.6 - 2 div.		
22.2 - 2 div	54.0	108.7
23.0 - 2 div.		
22.2 - 2 div		
89.0	? → 96.5	197.0
62.8 - 3 div.	a diffant drop →	
40.3 - 2 div.		
41.5 - 2 div.		
45.4 - 2 div.	31.4	62.4
43.0 - 2 div.		
170.2		
41.6 - 2 div.		
43.6 - 2 div.	—	80.4
45.2 - 2 div		
42.5 - 2 div		
172.9		
41.0 - 2 div.		
42.0 - 2 div.		
—		
—		
170.4	—	80.4
40.4 - 2 div		
44.2 - 2 div		
45.2 - 2 div.		
43.2		
173.0	—	37.4
130.4 - 6 div. = 173.9		
170.6		

Finished at 4:18

$V_1 = \frac{1022}{88} = .01161$ .00945 .194248 .064997-2

$V_2 = \frac{1022}{91} = .03798$ .00945 .011161 .049136 .044538 ÷ 11 = .003622 .51809-2

$V_3 = \frac{1022}{108} = .009402$ .00945 .011161 .021012 ÷ 8 = .002626 .03343 .976053-2

Mean = .003624

$V_5 = \frac{1022}{197} = .005187$ .00945 .011161 .016797 ÷ .71498-3

ε = 5.266 5.181 correct 4.8% low

.41901-3 .08245-1 .19430-2 .64981-7 2.92834- .72157-10

Volts at 4:20 = 833 + 13.8 = 846.8

$V_1 = \frac{1022}{171.4} = .005963$ .00945 .234201 .71544-3

$V_2' = \frac{1022}{197} = .005187$ .059630 .064817 ÷ 18 = .003601 ÷ 17 = 3912

$V_2'' = \frac{1022}{62.4} = .01638$ .05963 .07601 ÷ 21 = .003620 ÷ 20 = 3800

$V_3'' = \frac{1022}{80.4} = .01271$ .00945 1.905276 .059763 .077249 ÷ 20 = .003862 ÷ 14 = 3801

$V_5'' = \frac{1022}{37.4} = .02732$ .00945 1.537387 .059763 .086496 ÷ 24 = .003603 ÷ 23 = 3787

61 .003615

4) 15194 .003799

Differences

.07601 .64919 3.01118 .00373 (1)

7601 3119 .00367 (2)

.55411-3 .88702-2 .19838-3 .64418-7 3.92824- .71589-10

5.199

.5796 .8877 .1913 5556 4284 72 TH

5.462

4th Obs. at 5.10 t = 23.0 P = 75.75

G		F	
½ - d	whole d	½ d	whole d
17.0	34.0	—	16.2
—	34.2	—	19.0
—	34.2	11.6	23.0
—	34.2		

Volts at 4:25

1 - 833 + 13.8 = 846.8
2 - 832 + 13.9 = 845.9
3 - 731 + 18.0 = 749.0
4 - 842 + 13.1 = 855.1
5 - 808 + 15.7 = 823.7
6 - 827 + 14.3 = 841.3

4873 + 88.8 = 4961.8

$v_1 = \frac{1022}{34.15}$ .02997

$v_2 = \frac{1022}{16.2} = .06310$
.02997
.09303 ÷ 10 = .009303

$v_2' = \frac{1022}{19.0} = .05376$
.2997
.08369 ÷ 9 = .009299

$v_2'' = \frac{1022}{23.0} = .04443$
.2997
.07436 ÷ 8 = .009262

Mean $v_1 + v_2$ = .009288

Log $v_1 + v_2$ = -3.9679
½ " v_1 = -1.2388
-3.1483
-6.4048
3.6957
-10.7085

5.11 Correct = 5.209

2.45 %
2 % 2 ones

Error .5 % or less

.005187
.005463
.01115 ÷ 3 = .003702

.01638
.005963
.02234 ÷ 6 = .003720

.01271
.005463
.018673 ÷ 5 = .003734

.02733
.005463
.03279 ÷ 9 = .003700
4) .56
.003714

Log $v_1 + v_2$ = 3.5699
½ " v_1 = -2.8877
3.1983
-7.6559
2.9282
-10.7277

e_1 = 5.342 Correct value 5.65

5.5 % low

These good for a little one but give these very small ones I must alone consider still better

t = 23. P = 75.75

Obs. at 5.25

Volts at 5:15

1 - 833 + 13.9 = 846.9
2 - 832 + 13.8 = 845.8
3 - 730 + 16.0 = 748.0
4 - 842 + 13.1 = 855.1
5 - 807 + 15.7 = 822.7
6 - 827 + 14.4 = 841.4
4871 88.9 = 4959.9
88.9
4859.9

G		F	
½d.	D	½d	D
—	35.7	27.4	54.7
17.5	—	—	54.8
17.6	35.5		

.00945
.5514
-2.45805

$v_1 = \frac{1022}{35.6} = .02871$

.00945
7384
-2.27105

$v_2 = \frac{1022}{5475} = .01867$

5 | .04738

$v_1 + v_2 = .009476$

$\log v_1 + v_2 = -3.9766$
$\frac{1}{2}\log v_1 = -1.2290$
-3.1983
6.4039
3.6955
$\overline{10.7084}$

$\tau_1 = 5.110$ 5.267 = correct

3% low error .5%

Obs at 5:30 $\theta = 23.0$ $p = 75.77$

G	F	
4.746	14.0	—
4.832	14.0	27.6
4.860	—	27.4
4.822	13.6	27.2
4.776	—	27.4
4.842	13.6	27.5
6 | 28.878	37.4	75.6
4.813	37.6	75.0
	37.6	76.0
	15.0	30.4
	15.6	30.8
	—	30.8
	15.6	31.0
	15.6	31.0
	15.3	31.0
	15.6	31.0
	31.4	62.8
	31.4	62.8
	~~22.2~~	22.2
	—	22.2

$\frac{1}{4813 \times 1022} = .3098$

$v_1 = .01237$

$\log = 4.32708$

$\log v_1 = \bar{4}.66354$

$27.42 = .03649$

$\frac{1}{75.53} = .013244$

$\frac{1}{30.81} = .03246$

$\frac{1}{62.8} = .01592$

$\frac{1}{22.2} = .04505$

Finished at 5:58

Volts at 6:00 P.M.

1 - 832 + 13.8 = 845.8
2 - 831 + 13.7 = 844.7
3 - 726 + 18.0 = 744.0
4 - 842 + 13.1 = 855.1
5 - 803 + 15.9 = 818.9
6 - 827 + 14.4 = 841.4

4949.9

.3098	.3098
.03649	.013244
74 | .24927	69 | .321044
.003301	.003299

.3098	.3098
.3246	.1592
73 | .24026	68 | .22392
.003291	.003290

.3098
.4505
77 \| .25285
.003284

3301
3299
3291
3290
3284
5 \| 1465
.003293

mean =

This is by far most probable mean. If the series of drops had been thrown out we should have got mean = .3248. This does not agree so well with differences but is possible.

$v_1 + v_2 = .003365$

Differences

$\frac{1}{27.5} = .03636$
$\frac{1}{75.3} = .01323$ } .02313 ÷ 7 = .003304

$\frac{1}{30.4} = .03289$
$\frac{1}{76} = .01316$ } .01973 ÷ 6 = .003289

$\frac{1}{31} = .03226$
$\frac{1}{62.8} = .01592$ } .01634 ÷ 5 = .003268

$\frac{1}{22.2} = .04505$
$\frac{1}{62.8} = .01592$ } .02913 ÷ 9 = .003237

mean = .003275

and the true value is pretty more nearly mean of 1st 3 diffs i.e. .003287 since a 2 sec slip would error in last reading would make last dif come up to other 3

$\log v_1 + v_2 = \bar{3}.52700$
$\log v_1 = \bar{4}.66354$

3.1963
.6.3889
.3.6446
-10.6943

$e_1 = 4.449$ correct 5.030

1.7 % low

Obs. at 6;15 θ = 23. P =

G		F	
—	38.6		10.2
19.0	38.4		11.3
—	38.4		

Saturday Feb. 10th 1912 θ = 22 p = 75.40

Volts at 3:10 P.M.

G	F ½ d	whole d
	11.9	23.8
12.200	11.9	23.8
12.182	14.0	27.8
12.324	16.3	32.5
12.176	34.3	68.4
12.278	34.3	68.8
12.206		

Lost it at 3:33 P.M.

6 | 13 6 6
12.228

1 - 829 + 14.0
2 - 827 + 14.2
3 - 873 + 17.0
4 - 840 + 13.2
5 - 811 + 15.6
6 - 824 + 14.6
4904 + 88.6 = 4992.6

$v_1 = \frac{1.022}{12.228} = .08358$

$v_2 = \frac{1022}{23.8}$ .04294 / 08358 = .126521 ÷ 23 = .5501

$v_2' = \frac{1022}{27.8}$ .036763 / 08358 = .120343 ÷ 22 = .005470

$v_2'' = \frac{1022}{32.5}$ = .031446 / 08358 = .115026 ÷ 21 = .005476

$v_2''' = \frac{1022}{68.6}$ .014899 / 08358 = .098479 ÷ 18 = .005471

Differences
115026
098479
3 | .016547
.005516
by far most reliable

.126521
.120343
.006178

.120343
.115026
.005217

mean .005697

Mean weighted $v_1 + v_2$
= .005493

Log $v_1 + v_2$ = 3.7374
½ " v_1 = 1.4611
-3.1983
6.3968
3.6983
-10.6985

4.994
23
c₁ 4.971 const = 5.109

2.7 % low.
% low 1.2 %

2nd Obs @ 3:45
Blue drop.

$\delta = 32.$ $p = 94.4 - 19 = 75.40$

Volts at 3:35
1-828+14.3
2-827+14.2
3-772+17.0
4-839+13.7
5-817+15.4
6-822+14.6
4899 +88.7 = 4987.7

G.		F	
½ D.	D	½ D	D
28.0	56.4	16.4	32.8
27.7	56.4	—	18.4
28.0	56.0	27.4	54.8
27.8	56.2 ←	~~27.6~~	~~55.2~~
		16.6	33.0
27.7	56.0	27.0	53.8
	10		18.40
mean	56.2		32.90
			54.30

$\frac{1}{56.2} = .01779$

$\frac{1}{18.4} = .05435$
$.01779$
$.03656 \div 6 = .012023$

$\frac{1}{32.9} = .03040$
$.01779$
$.04819 \div 4 = .012047$

$\frac{1}{54.3} = .01842$
$.01779$
$.03621 \div 3 = .012070$
$3 \overline{)140}$
$.012065$

$5.5015 - 1$

$\frac{1}{2}\log(.01779) \rightarrow .08013 - 2$
$\frac{1}{2}\log 4 \rightarrow .00945 -$
$.12509 - 1$
$.00472$
$.19830 - 3$
$.41769 - 6$
3.69793
$.71976 - 10$

5.2444
± 25
~~5.2525~~

5.222 5.363 = correct

2.8% low

error 4%

3rd obs - 3.157. θ = 22,1 p = 75.36

white - nearly reddish. Volts ab - ΔM.

G		F		
1/r	W	1/r	whole.	
31.7	64.4	22.0	43 2	1
31.7	64.4			2
31.7	64.0			3
				4
				5
				6

4th Obs at 4:14 $\theta = 22.1$ $p = 75.40$

Volts at 4:30

Stop watch	G Grav	F ½	F D
14.9	15.282	14.0	27.3
	15.286	13.6	26.6
	15.360	14.0	27.2
15.6		16.3	32.4
14.9	15.308	—	20.380
		10.2	20.4
45.4 / 15.13	15.228	11.6	22.8
	15.340	27.0	53.0
		38.0	77.0
		38.6	77.5
	15.334	26.4	53.0
	7 | 2138 / 15.305		

Finished at 4:25

$\frac{1}{27.03} = .03700$ — 2) .06644 / .03322

$\frac{1}{32.4} = .03086$ — 2) .01845 / .00150

$\frac{1}{20.28} = .04931$ — 2) .02444 / .006208

$\frac{1}{22.8} = .04386$ — 2) .03044 / .006089

$\frac{1}{53} = .01887$

$\frac{1}{77.3} = .01294$

.005930
6) .03639
.006063

828 + 14.3
827 + 14.2
764 + 17.6
839 + 13.2
808 + 15.7
819 + 14.9 — 49749
4885 + 89.9 = 49749

Differences
.5930
.6089
.6150
mean .006056

$\frac{1}{15.305} = .06534$; .03700; 17) .10234; .006020

.06534; .03086; 16) .09620; .006012

.06534; .04931; 19) .11465; .006034

.06534; .04386; 18) .10920; .006067

.06534; .01887; .08421; .006015

.06534; .01294; .07828; .006022

mean = .006027

$v_1 = .06677$
$\log .06534$
$\bar{2}.8152$

$\bar{3}.7797$
.00495
$\bar{1}.4076$
.00472
3.1983
−6.39977
3.6971
−10.70767

5.043
20
$e_1 = 5.023$ Correct 5.136

2.5% low

Error .3%

5th Obs. at 4:40 $\theta = 22.1$ $p = 94.6 - 18.9 = 75.7$

watch chronograph

G		F	
	18.344	93.4	187.4
	18.356	41.6	83.2
		42.4	84.1
	18.373	16.0	31.6
	18.376	16.2	31.8
18.4		27.0	54.2
	18.422	42.0	83.8
	18.362		
6	223.3		
M	18.372		

$\frac{1}{18.372} = .05444$ $v_1 = .055638$

Finished at 5:00

$\frac{1}{187.4} = .005336$
5444
.05977 ÷ 9 = .006641

$\frac{1}{83.65} = .011953$
5444
.066395 ÷ 10 = .006639

$\frac{1}{31.7} = .03155$
5444
4599 ÷ 13 = .006614

$\frac{1}{54.2} = .01845$
5444
.07289 ÷ 11 = .006626

$\frac{1}{83.8} = .01193$
5444
6637 ÷ 10 = .006637
57.1557
.006631

Differences

.01845	.03155	.03155	.011953
.01193	.01845	.011953	.005336
.00652	2).01310	3).019695	.006617
	.00655	.006532	

mean = .006555

Log .006631 = −3.82155
.00945
−1.36795
−3.1963
−6.39725
−3.6963
−10.70095

2.7359
1.866

5022
20
$e_1 = 5.002$ Correct =

110

6th Obs at 5:05.

$\theta = 22.2$ p 94.6 − 19.1 = 75.5

G		F		
watch	chro-	1/2	2	
	4.610	—	33.6	33.93
	4.686	17.0	34.0	$\frac{1}{34.2}$ = .02934
4.6		17.2	34.2	= .016342
		30.4	61.2	61.20
		13.0	25.7	$\frac{1}{25.7}$ = .03891
		12.8	25.8	
		12.6	25.6	25.73
			25.696	$\frac{1}{25.76}$ = .03882
			25.838	
		39.3	79.4	$\frac{1}{79.41}$ = .012589
			79.416	
	4.694			$\frac{1}{17.26}$ = .05794
	4.684		17.162	17.26
	4.754		17.344	
	4.732			
	4.760			
	4.658			
	4.706			
	4.732			
	4.680			
	4.766			
	4.768			
	4.762			
	4.700			
	4.744			
	4.690			
	4.696			
	4.644			
	4.662			
	14126			
	4.7058			

mean = 4.7058

Finished 5.30

Volts at 5:30

1 − 827 + 14.4
2 − 826 + 14.6
3 − 754 + 18.0
4 − 838 + 13.3
5 − 806 + 15.8
6 − 819 + 14.8
4870 + 90.9 = 4960.9

Differences

.02934	.03891	.03882	.05794
.01634	.01634	.01259	.01259
4) .01290	7) .02259	8) .026231	14) .04535
.00330	.003224	.003279	.003240

3300
3224
3279
3240
4) 13043
.003261 = mean diff

.2125	.2125	.2125	.2125
.01634	.03882	.01259	.05794
7) .22884	7) .25132	6) .22509	8) .27044
.003269	.003264	.003262	.003260

mean = .003263

Log
−3.51362
.00945
−1.66540
3.1983
6.38977
3.69548
−10.69429

4.9465
.20
e_1 = 4.927 corrd = 5.029

2% low.

$\frac{1}{4.706}$ = .2125

V_1 = .21717 log = −1.33680
−1.66540

7th obs - at. 5:37 $\delta = 22.3$ $\rho =$ (45)

G		F	
~~½~~	d		
~~49.0~~	~~60.0~~		
~~69.0~~	~~59.8~~	~~1570~~	18.0
29.0	57.7	—	31.8
—	57.5		
		263	52.0
28.7	57.7		
	57.63		

~~$\frac{1}{2} = .1667$~~

$\frac{1}{18} = .05556$

$\frac{1}{31.8} = .03145$

$\frac{1}{52} = .01923$

$\frac{1}{57.63} = .01735$

$v_1 = .01773$

$\log = -2.248704$

$\frac{1}{2}$ " $= -1.12435$

Differences

.05556	.03145
.03145	.01923
.02411	.01222

mean = .01211

.05556	.03145	.01923
.01735	.01735	.01735
.07291	.04880	.03658

6 | 4 | 3

.01215 .01220 .01219

mean = .01218

$\log .01220 = -2.08565$

-1.12435

.00945

3.1983

-6.41775

3.69513

-10.72262

Volts = 4456

5.2801

164

$e_1 = 5.2637$

5363 = coul

1.9% low.

error 5%

4/8th Obs at 5:57 P.M. θ = 22.2 P 943-19.4 = 759

Volts at 6.23

G	F 1/4	F D
	18.3	36.4
	15.6	30.7
	—	82.2
	18.3	36.4
11.112		
11.056		
11.176		
11.144		
11.146		
11.124		
11.126		
11.086		
11.088		
11.086	12.0	23.4
11.160	—	26.4
→ good 11.168	13.0	26.4
	13.6	26.6
11.124		
11.196	18.4	36.4
	18.8	37.2
11.146	18.3	36.7
11.084	42.2	83.7
11.134	10.6	20.8
9.8 / 11)121.56 / 11.127		

Finished at 6.21 P.M.

1/30.7 = .03257

1/36.4 = .02747

1/82.2 = .01217

1/23.4 = .04274

1/26.49 = .03769

1/36.8 = .02717

1/83.9 = .01193

1/20.8 = .04808

1/11.127 = .08987

v_1 = .09185 Log = -2.963066, -1.48154

826 + 14.6
825 + 14.5
752 + 12.0
837 + 13.4
802 + 15.9
819 + 14.8
4861 + 91.2
= 4952.2

Differences.

.03257 − .02747 = .00510

.02747 − .01217 = 3)01530 = .00510

.02717 − .01193 = 3)01524 = .05[illegible]

.04808 − .01193 = 7).03615 = .005165

.03769 − .02717 = .01052

.03767 − .02717 = .1050

Taking the 4 big groups
.00510
510
508
5165
mean .005111

.03257 + .08987 = 24).12244 = .005102

.02747 + .08987 = 23)11734 = .005102

.01217 + .08987 = 20)10204 = .005102 (.24)

.04274 + .8987 = 26).13261 = .005100

.03769 + .08987 = 25).12756 = .005102

.02717 + .08987 = 23).11704 = .005090

.01193 + .08987 = 20).10180 = .005090

.04808 + .08987 = 27).13795 = .005109

5102
5102
5102
5100
5102
5090
5090
5109
8)40797
5100

Log .005100 = -3.70757
.00945
-1.48154
3.1983
-6.39686
3.69 4781
-10.70408

error not over .4%

Mean 5036 (1.4) e_1 = 5.018

corrected = 5098

1.69% low

Tuesday - Feb. 13th 1912 — θ = 23.0 p = 94.6 - 18.8 = 75.8 (43)

First Observation → Volt bat 3.40 P.M.

857 + 12.0
858 + 12.0
844 + 12.9
856 + 12.0
839 + 12.8
849 + 12.1
5103 + 73.2 = 5176.2

(51)

G	F
	17.514
	17.5
	46.724
	46.494
4.346	18.722
4.400	18.616
4.310	
4.376	56.280
4.370	56.276
4.422	
4.392	21.362
4.290	21.476
4.392	
4.360	58.936
4.346	58.194
4.368	58.456
4.350	58.904
13) 47 22	20.412
4.863	20.404
4.324	20.322
$\frac{1}{4.328}$ .2308	
	10.710
	10.660
	20.290
	20.296

$\frac{1}{17.51}$ = .05711

$\frac{1}{46.62}$ = .02145

$\frac{1}{18.67}$ = .05356

about 2 min elapsed

$\frac{1}{56.28}$ = .01777

$\frac{1}{21.42}$ = .04671

$\frac{1}{58.62}$ = .01706

$\frac{1}{20.380}$ = .04904

$\frac{1}{10.69}$ = .09355

$\frac{1}{20.293}$ = .04926

Differences

V_1 = .23565

Log −1.37227, −1.68613

Finished at 4:32

5,=4.877

34% low

.01615 = $\frac{b}{a}$

2252 = $\frac{1}{pa}$

2nd Observation 4:45 A = 23.00 $p = 94.7 - 18.7 = 76.0$

Red drop

Volts at 4:30

855 + 12.0
856 + 12.0
840 + 12.7
855 + 12.0
834 + 13.4
847 + 13.0

5087 + 75.1 = 5162.1

49

G	F	
10.3 – 1st div 21.2 – 2nd div 31.6 – 3rd 42.3 – 4th 53.0 – 5th 63.6 – 6th 74.3 – 7th 84.6 – 8th		
10.3 10.9 10.4 10.7 10.7 10.6 10.7 10.3	19.6	
8) 84.6 10.57		
42.3 85.2	28.570	
42.3 85.1		
within 5 div of plate	within 5 div & walls diverge & bottom of plate	
9.8 9.8	35.6 – 35.6	
20.0 10.2	71.0 – 35.4	
30.8 10.3	104.0 – 33.0	
41.8 11.0	137.3 – 33.3	
51.6 10.3	169.4 – 32.1	
62.6 11.0	200.6 – 31.2	
73.0 11.0	232.6 – 32.0	
84.0 11.0	265.0 – 32.4	
10.9 10.9	5 – 33.3 – 33.3	
21.6 10.7	70.3 – 37.0 – 36.0	
31.7 10.1	37.0	
— 10.2	35.6	
13) 136.5 10.54	8.479 24.00 4 27.2	
10.3 – 10.3 20.5 – 10.2 31.0 – 10.5 41.0 – 10.0 52.0 – 11.0 62.4 – 10.4 73.0 – 10.6 83.6 – 10.6 10.3 – 10.3 21.0 – 10.7 31.6 – 10.6 42.3 – 10.7 10.492	mean = 10.5 and 8.476 $\frac{1}{84.16} = .01188$ $v_1 .01214$ log v_1 = –2.0842 $v_1^{1/2}$ = –1.0421	

5:23 P.M.

$\frac{1}{19.6} = .05102$

$\frac{1}{28.57} = .03501$

$\frac{1}{272} = .003676$

.05102
.03501
2) .08603
.04301

.03501
.003676
.031334
.015667

.01188
.05102
4) .06290
.01572

.01188
.03501
3) .04689
.01563

.01188
.003676
.015556

.01566
.01563
.01556
3) .04685
mean .01560

$e^{2/3}$
3) –10.7299
–4.99100
7.8300
$66.07 = e^{2/3}$

log .0156 = –2.1931
00945
–1.04711
3.1963
–6.44296
3.71307
–10.72989

5.364 correct = 5.469

1.867 % low

error .5 %. Most reliable drop one yet worked on.

$l = .000009416$
a
–1.64270
3.72299
–2.0842
–14.2411
–2.2026
3) –12.4385
–4.0128
1.8808
–3.8936
2.1064

–4.8547
1.8808
–6.9789
–4.0128
–2.9611
$.09144 = \frac{l}{a}$
$.0001030 = a$

$127.8 = pa$

3rd Observation — 5:38 $\theta = 23.0$ $p = .946 / 16.75 / 75.75$ (41)

Blue drop — Volt at 5:25

G	F
22.824	7.610
22.890	4.400
22.818	30.2
22.770	36.683
22.774	
5) 4026	
22.8005	

Finished at 5:45

Volt at 5:25
849 + 12.9
852 + 12.4
836 + 13.5
851 + 12.9
830 + 14.1
842 + 13.1
5060 + 79.4 = 5139.4

Volts at 5:50
846 + 12.2
851 + 12.0
834 + 13.4
851 + 12.0
829 + 14.3
841 + 12.6
5052 + 76.5 = 5128.5

$\frac{1}{22.8} = .04386$

$\frac{1}{30.2} = .03311$

$\frac{1}{36.68} = .02726$

$\frac{1}{7.610} = .1314$

$v_1 = .044825$
$\log = -2.65152$
$\frac{1}{2}\log = -1.32576$

$v_2 = .02786$
.072685

$\log v_1 + v_2 = \bar{2}.86145$
-1.32576
-3.1983
5.38551
-3.71029
-9.67522

9) 47.34
52

t_g: 848, 845, 840 — 8427
t_F: 846, 28.890, 2770
n': 3, 3.2 — .01578, .01565 — .03143, 1571
n: 4, 3, 8 — .01570, .01561, .01554 — 1562

$\frac{1}{8427} = .01186 \times 10^{-1}$; $v_1 = .01219$
$\log = -2.0831$; $\frac{1}{2}\log = -1.04155$

$v_1 + v_2 = .01564 \times 10^{-1}$ = .01545
$\log = -2.2028$, -1.04155, -3.19776, -6.44231, 3.7134, -10.7307

$\frac{1}{146} = .5102$
$\frac{1}{286} = .3497$
$\frac{1}{370} = .01676$

.04386
.03311
.07697
1022
15394
15394
7697
.0786634 $= v_1 + v_2$

$e_1 = 5.374$
3)14.4614
4.8205
$e_1^{2/3} = 66.14$

.5102, 3676, 3) 47344, 1578
.5102, 3497, 1805
3497, 3676, 3) 7348 (?), 1565
1166, 3497, 1166, 1156, 15) 23.43 / 4683, 1561
5102, 1166, 4) 6268, 1592

a:
-16.4209
3.7114
-2.0831
-14.2154
-2.2028
3) -12.0126
-4.0042
-1.8808
-3.8858
4.1150
.0004687 = a

1303 $= \frac{1}{pa}$

$\log v_1 + v_2 = \bar{2}.8957$
$\frac{1}{2}\log v_1 = -1.3257$
3.1983
-5.4197
-3.7103
-9.7094

e_1, 10) 51.22
$e = 5.122$ Corrected 5.184, 5.122

Something the matter with the 36.683 speed
This computation is for the 30.2 speed

Rest of Worked up Aug 24 Middlesworth
6.038, 134, low