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 TWO:
March-April 1912

PART 3 OF 3
From page 60 to page 84

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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

Administrative information

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http://resolver.caltech.edu/CaltechLN:LN_Millikan_R_2

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54) Saturday Apr. 13, 1912

Fount Obs'd. 9:20 P.M.

Start, $\theta = 22.95$

End, $\theta = 23.0$

5.58 P.M.

$p = \frac{94.60}{18.72} = 75.87$

G		F
28.456	32.2 – 63.2	62.938
14.3 – 28.4		
28.562	31.6 – 62.8	62.634
14.2 – 28.5	31.4 – 62.8	
28.468		40.734
14.2 – 28.6	20.6 – 41.0	
28.560	62.6	62.308
– 28.4		
28.610	31.0 – 62.2	62.870
– 28.7	12.2 – 24.3	24.480
28.634		
14.3 – 28.5	15.2 – 30.4	30.424
28.624		
14.2 – 28.6		
28.628		

$8\overline{)45^{5}42^{3}}$

28.57

3

28.860

$\frac{1}{2860} = .03497 \times 1021 =$

$v_1 = .035704$

$\log = -2.55275$

$L_{11} = -1.2764$

$\frac{1}{62.90} = .01590$

.008610

9.55 P.M.

$\frac{1}{40.80} = .02451$

– .008560

$\frac{1}{62.7} = .01595$

$\frac{24.90}{13} = 1.917$ .008300

$\frac{1}{24.78} = .04085$

$\frac{1}{30.45} = .03284$ Mean $= .008476$

$dV =$

$V_1 + V_2 = .008473 \times 1021$

$= 8.651$

$\log = -3.93705$

-1.27638

3.19983

6.41173

3.70198

-10.70983

$e_1 = 5.12.6$

$e_1 = 5.1220$

a	l
-16.4270	
3.7019	
-2.5528	-4.8547
-14.6817	1.8801
-3.9370	-6.9746
-1.27447	-4.2482
-.42482	-2.7264
1.8801	.0532.6 = $\frac{1}{a}$
-2.1283	.05390 = $\frac{l}{a}$
1.8717	$\frac{74.42}{74.97} = \frac{1}{\lambda_0}$

$\frac{.0001771 = a}{\frac{1}{1962} = a}$

$e^{\frac{1}{3}}$

-10.70483

$3\overline{)-19.41966}$

7.8066

$6405 = e^{\frac{1}{3}}$

$6400 = e^{8}$

3% low.

42

$1 + A\frac{l}{a} = .6452$

$\log = .0192$

3

$2\overline{)05576}$

.00585

70963

02613

88107

$e^{\frac{1}{3}} = 4.7795$

832.5 + 13.8

838.0 + 13.4

837.0 + 13.0

817.5 + 15.1

837.0 + 13.0

838.0 + 12.9

5000.0 + 81.2

= 5081.2

8300 + 14.2

838.0 + 14.0

820.5 + 14.8

814.5 + 15.3

827.5 + 14.4

8300 + 14.2

4953.5 + 82.9

5036.4

3497 3497

3244 4085

8 | 6781 9 | 75852

8476 8425

3497 3497

1595 2451

6 | 50927 | 5948

8487 8497

3497 8478

1590 8487

6 | 50870 8425

8478 8476

51363

8473

Saturday, April 13, 1912.

Fifth observation

10:00 P.M

$\theta = 23.0\ ^\circ C.$

$p =$

$p = \frac{9471}{1665}$

9:48 P.m.

G	F	
18.626		
18.716	12.6 - 24.7	24.722
18.602		21.206
18.634	-21.0	21.110
18.696		
18.678	-72.8	72.540
18.598	-36.6	36.454
18.612	24.6 - 49.1	48.870
18.622		
18.795	72.0 - 143.1	142.838
18.732	36.6 - 72.4	72.428
18.780	-37	36.722
18.736	-36.4	36.652
18.754	-36.7	36.662
18.712	140.6	140.891
18.760	76.3	
18.716	23.6 - 48.0	48.302
18.740	48.4	48.266
18.695	10.6	20.942

10:55 P.M.

Beauty Pulpit

8300 + 14.7

8290 + 14.3

8200 + 14.8

8135 + 15.5

8220 + 14.7

8295 + 14.3

4944.0 + 87.8

5031.8

56

Saturday Apr. 13, 1914 θ = 23.25 $\phi = \frac{9480}{1653}$ 70.27

Sixth Observation at 11.05 Volts at 10.55

G	T	
15.404		
15.314		14.544
15.372		
15.358		
15.356	37.6 – 74.9	74.640
15.344	37.1 – 75.2	74.872
15.380	35.6 – 51.2	51.412
15.436	36.0 – 51.4	51.186
15.356	37.2 – 74.4	74.130
15.292	– 74.2	74.058
15.326	– 38.8	37.930
	36.9 – 73.4	73.142
15.474	36.6 – 73.2	73.122
15.420		19.974
15.424		20.004

8290 + 14.3
8260 + 14.5
8180 + 14.9
8125 + 15.6
8170 + 15.0
8270 + 14.4
4929.5 + 88.7
5018.2

11:34

L

-4.8547
1.8824
-6.9723
-4.3863
-2.5860

-16.4209
37002
-2.8122
144494
-3.7936
-11.1588
-4.3813
18524
-2.2687
1.7913

$\frac{e}{a} = .03891$

$\frac{1}{\beta a} = 5408$

$e_1 = 5010$

$e^{\nu_1} = 6308$

$e = 4.779$

Saturday, Apr. 13, 1912
Seventh Obs. at

θ = 23.22

V. Ck at 11:35 P.M.

G		F	
40,518		17.760	
40.522	32.0 – 63.2	63.100	
40.387	96.4 – 174.4		
40.542			
40.650	14.8	15.138	
40.696	14.0 – 28.0	27.716	
40.478		15.060	
40.458	38.4	38.606	
40.494	38.4	38.387	
40.803	86.4 – 172.2	172.626	
404.542			
40.54		12:28 A.M.	
4060			

1/426 = .02463 × 1021 = .025147

log = -2.5005

½ ll = -1.20025

Brady forecast

e^{y_2} = 61.01

(10)

(14)

(1/1926 = .05231) (1/6323 = .01582) (1/277.74 = .03605) (1/1506 = .06641) (1/38.53 = .025955)

(Rec. ⅔ speed of clockwork)

827.0 + 14.4'
825.0 + 14.5
818.0 + 14.9
813.0 + 14.9
814.5 + 15.3
826.5 + 14.5
4924.0 + 89.0
89.1
5013.0

826.5 + 17.5
825.0 + 14.6
817.0 + 15.0
812.0 + 15.6
809.0 + 16.0
821.5 + 14.7
4911.0 + 90.4
90.4
5001.0

12:30 →

v, v₂ = .01012 × 1021 = 01033

log = -2.01470
-1.20025
3.19983
-6.48275
3.69940
-10.71325

a: -16.4270, 3.6991, -2.4002, -14.5263, -2.0141, 31-125122, -4.1707, 1.8832, 2.0539, 1.9461

l: -4.8547, 1.8832, -.69715, -4.1707, -2.8008

5.1675 / 5 = e₁ = 5.1725 = 5.168

(1 + 4.8449/2) = 1.05367

log = .022705 / 3 = 2).068115 = .034057

7137 / 5340 / 6997

e = 4.783

e^{y_3}

-10.7137 → 7133 / 2)19274 = 7.8089 / 7.8091 / 6443 / 64.440 = e^{y_3}

58) Monday Apr. 5, 1914 θ = 23.23 p = 6182 6141 / 5831 5831 / 3.17 3.10

First Observation at 5:00 PM. Volts at 5:00 P.M. 840.01 / 12.7 / 852.7

G	F	G	F
10.6 (2)		52.4	{21.6}½ {41.8}
15.4 (4)			
12.6 (6)		51.6	{20.6} {41.4} = t
12.8 (8)	14.8		
51.4			
13.0 (2)		51.32	1/51.32 = .01944 coef = .01944 × 1.031
12.4 (4)			
13.6 (6)			5.40 P.M.
12.2 (8)	14.6		
51.0			
13.0 (2)		14.73	1/14.73 = .06789 } .02185
12.6 (4)			
12.0 (6)			
13.0 (8)	21.6		
50.6			
12.4 (2)		21.7	1/21.7 = .04604
12.8 (4)			
12.6 (6)			
12.6 (8)	21.6		
50.4			
13.0 (2)			.04387 / 2 = .02194
13.0 (4)			
12.0 (6)			
13.4 (8)	21.9		
51.4			
13.2 (2)		4607	1/4607 coef = .02170 = .02166
13.6 (4)	116.0 (2)		
12.8 (6)	117.2 (4)		time taken together
13.0 (8)	117.5 (6)		
51.6	110.3 (8)		
	460.7		
13.0 (2)	110.0 for 4 div.		
12.6 (4)	21.4 for distance		
	41.9 for hole disk		
52.4			
	21.0 = ½		1/41.7 = .02397 coef = .02392
	41.8 = 1		
50.4	14.8		

Difs: .02175, .02185, .02194 / 3).06554 / .02185

.01944 / .00217 / .02161 = .04336 / .02168

.01944 / .02392 / 4).08733 / .02183

.01944 / 4604 / 3)1.06548 / .02183

.01944 / 6789 / .02183, .02168, .02165, .02161 / 4).08795 / .02199

$V_1 = .01985$

$\log_{10} V_1 = -2.2978$

$\frac{1}{2}\log_{10} V_1 = -1.1489$

$V_1 V_2 = .02174 \times 1.031 = .02220$

$\log_{10} = -2.3464$

$\frac{1}{2}\log_{10} = -1.1469$

-3.1983

-6.8936

2.9296

9.7640

$V = 5.813$

$e^{\frac{1}{2}}$

58.07 / 6 — 9.7644

$e_1 = 5.813$ — 3)17.5288 / −6.5096

$e_1 = 58.06$ — 3234 = a / 3 / 3231 = $e^{\frac{1}{2}}$

a: −16.4209 / 2.9296 / −2.2978 / 15.6483 / −2.3464 / 13.3019 / −5.7673 / −4.2601 / 3.7398

l: −4.8579 / 4938 / −4.3619 / −5.7673 / 10.5946 / 3.932 = l / 3929 = l/2 / 5851 = a

5443 = $\frac{1}{2}$ / 5484 = $\frac{1}{2}$

No 70

Monday, Apr. 15, 1912
Second Observation
6:05

θ = 23.21 p = 6204 / 5758 / 4.46

Volts at 5:50 P.M. 837.5 / 13.0 / 839.5 / 12.8 / 1702.8

G.				
5.092		19.480		
5.010	19.6	19.356	1/1933 = .05173	
5.052	19.4	19.374		
5.044		19.202	.02744	.01783 ÷ 9 = .0019
	14.6 - 29.0	29.214	1/2902 = .03446	
5.044	14.6 - 28.9	29.022		
5.030	- 28.9	28.686	822/2381 = .3452	.00901025 = .001802
	19.6 - 39.0	38.688	1/3873 = .02580	
5.066	19.6 - 38.6	38.620		.01250/7 = .001786
	37.7 - 75.7	75.136	1/7519 = .01330	
5.120	37.0 - 73.8	73.754		
	37.0 - 72.8	72.758	1/7290 = .01372	.01653/9 = .001837
5.046	16.6 - 33.2	33.034	1/3306 = .03025	
5.128	16.3 - 32.8	32.788	1/32.50 = .03047	.00549 ÷ 3 = .001830
	- 39.8	39.956		
4.912	24.0 - 47.1	46.793	1/40.03 = .02498	.00365/2 = .001825
5.036	40.6 - 80.9	80.820	1/4658 = .02133	.00698/5 = .001796
	- 80.0	80.152	1/8096 = .01235	
5.080	22.0 - 55.2	55.206	1/8831 = .01245	.00563/3 = .001877
5.122	17.2 - 34.4	34.398	1/55.32 = .01808	.01094/6 = .001823
708.127			1/34.46 = .02902	
5058				
19				
5.099				

Dito

	1823
	1977
	1796
	1837
	1786
5	9119
	1824

Volts at 6'40 P.M. 836.0 / 13.1 / 837.0 / 13.0 / 1699.1

1/5099 = .1984 × 1021 = .202 56

log = -1.3065 / log = -1.6538

a: -16.42 99 / 32869 / -13065 / -14.5578 / -3.6497 / -11.6881 / -4.5627 / .6493 / -3.2120 / 2.7891

l: -4.6597 / .6493 / -4.2054 / -4.8547 / -1.6427 / .0003653

.4392 = l/a / .4396 = Tan Com / .4396 = l/a

6137 / 6249 = 1/μ / 6372 = Tan Com / 6142 = 1/μ

Patch
Permits for corporate officers to attend meetings of directors

No 56

Thus we proceed to solve

ak: -10.46136 / 3.2304 / -7.23176 / -3.2497 / -4.4527 / -4.5627 / -1.9499 / 1.3880 / -.5620 / -.1740

e = 2.7777 / 2.7777 / 7777 / 7777 / 7777

b = .6069 / .6240 / .3539 / .6227 / .9766 / .9405

A = .5720

Cont = 1823
V1+V2 = 1823+1021 = .001861

log = -3.2697 / -1.6533 / 3.1978 / -6.1208 / 3.2304 / -10.8912

8908 / 7.9272 / 8457 = e^x / 8457 = e^x/3

60/ Monday Apr. 15, 1912.
Third Observation
at 8:55 P.M.

$\theta = 23.05$

Volts at 8:45

$p = $ 6221 / 5738 / 483

824.5
14.6
832.0
13.8
1684.9

G		F
17.236	~~8.6 – 17.2~~ 20.5	20.118
16.990	10.6 – 20.5	20.346
16.992		20.298
		20.386 →
16.972		
17.012		25.104
16.912	25.0	25.256 →
17.130	25.6 – 50.4	50.384
17.184	25.6 – 50.2	50.152
17.048	25.3 – 50.0	50.620 →
16.924	12.6 – 25.4	25.368 →
16.994	97.6 – 194.8	194.8 →
17.062	33.9 – 66.9	66.662
17.030	66.9	66.654 →
17.022	40.6	40.662
17.022	40.2	40.130 →
		50.2 (2)
		49.1 (4)
		48.4 (6)
		48.6 (8)
		196.2 →
17.106	25.6 – 50.2	50.206

16 / 272.856
17.053

$\frac{1}{20.30} = .04926$ } .00458

$\frac{1}{25.20}$ .03968

} $\frac{.02495}{5}$ .004908

} $\frac{.01967}{4} = .004967$

$\frac{1}{50.48} = .01981$

} $\frac{.01956}{4} = .004890$

$\frac{1}{25.40}$ .03937

} $\frac{.034437}{7} = .004891$

$\frac{1}{194.8} = .005133$

} $\frac{.009857}{2}$ .004929

$\frac{1}{66.71}$ .01499

} $\frac{.00971}{2} = .004855$

$\frac{1}{40.48}$ .02470

} $\frac{.019605}{4} = .004901$

$\frac{1}{196.2} = .005095$

} $\frac{.014835}{3} = .004942$

$\frac{1}{50.21} = .01992$

8 | 39283
.004910

.05866 / .01992 / 16 | .07858 / .004911

5866 / 5095 / 21 | 63752 (?) / .004904

5866 / 2470 / 17 | 8336 / .004904

5866 / 1499 / 15 | 7365 / .004910

5866 / 5133 / 13 | 63793 (?) / .004907

5866 / 3937 / 49803 (?) / .004901

5866 / 1981 / 16 | 7847 / 4905

5866 / 3968 / 20 | 19837 / 4917

5866 / 4926 / 22 | 10792 / 4906

4906 / 4917

4906 . 20 time
4912 25.3
4905 50.0
4905 194.8
4910 66.9
4904 40.2
6 | 42
.004907

$v_1 + v_2 = .004907 \times 1.021$
$= .005010$
Log = −3.6998
−1.3887
−3.1977
−6.2862
3.2264
−9.0598

$\frac{1}{17.053} = .05866 \times 1.021$

$v_1 = .05989$
log = −2.7774
log = −1.3887

9:45

Beauty to those agreement between two methods of getting $v_1 + v_2$
Publish only

No 63

a
−16.4299
3.2264
−2.7774
−14.4247
−3.6998
3 | −12.7249
−4.2416
.6839
−4.9255
+3.0745

.0001195 = a

l
−4.8547
.6839
−4.1708
−4.3966
−1.9299

.8496 = l / a

ak
10.46136
3.2264
−2.56776
−3.6998
−5.98796
−2.2456
−1.74696 = log ak

log
.2504 = log $\frac{l}{k}$

1.799 = $\frac{1}{k}$
.793 = $1 - \frac{l}{k}$

log = −1.5993
2.0745
−4.5248

b = .00006546
b = .00006680 (?)

−1.5993
−1.9382
−1.9702 (?)

1149
1189 = $\frac{1}{pa}$

long 22 cm.

$e_1 = 11.485 \times 10^{-10}$

$e^{2/3}$
−9.0598
3 | −28.1196
−6.0399
1096 = e_1

$\lambda = .9336$

No 63

Monday Apr. 15, 1912

Fourth Observation.

at 10:00 P.M.

θ = 23.06

p = 6279 / 5705 / 574

Volts at 9:45 824.0 / 832.0 / 14.2 / 13.8 / 1684.4

G	F	
43.534 (34.6 / 34.4)	16.670 (16.4)	} 1/1663 = .06013 } .01152
43.512 (43.4 / 43.6)	16.594 (16.6)	
44.010 (44.1 / 44.0)	20.566 (20.4	1/20.57 = .04861

3 | 131056
43.685
.064
43.75

10:10 P.M.

1/43.75 = .02286 × 10²¹

= v_1 = .02334

Log = -2.3681

1/11 = -1.1841

.02286 / .06013 / 7 | .08299 / .01185

2286 / 4881 / 6 | 7147 / .01191

1141 / 1185 / 1152 / 3 | 3478 / 1176

$v_1 + v_2$ = .01186 × 10²¹ = .01200

Log = -2.0792 / -1.1841 / -3.1978 / -6.4611 / 3.2264 / -9.2347

v = 1684

e = 17.27

e_1 = 17.17

$e^{2/3}$

a

-16.4209 / 3.2264 / -2.3681 / -14.0154 / -2.0792 / 3 | -13.9362 / -5.9787 / 7356 / -4.7148 / 3.2859

l

-4.8547 / 7356 / -4.1191 / -5.9787 / .1404 / 1.3681 = 1/a

.00009523 = a

1931 = 1/λ

-9.2347 / 3 | -18.4694 / -6.1565

1560 × 10⁻⁹ = $e^{2/3}$

1559 = $e^{2/3}$

1444 = $e^{2/3}$

1434

ak

-10.46136 / 3.2264 / -7.68772 / -2.0792

Log k -5.60856 / -5.97187

Log k -1.62956

Log 1/k = .37014

1/k = 2345

1 - 1/k = 1.2345 = b/λa

Log -1287 / 3.2359 / -9.8430

b = .0006967

.1287 / .1417 / -1.9870

A = 9705

Avg 2nd

No 67

(27) Monday Apr. 15, 1912

First Obs. at 10:24

$\theta = 23.07$ $p =$ 6262 5602 570

Volts at 10:12

824.0
831.5
14.6
14.0
1684.1

G		F		
(12.6 / 348)	25.058			
(12.6 / 252)	24.550	18.5 – 36.9	37.130	1/37.00 = .027 03
	25.036	36.8	36.794	.00598 ÷ 1 = .00598 0
	25.070	24.2 – 47.8		
(12.6 / 252)	24.468	23.6 – 47.4	47.414	1/475 = .02105 .01975 ÷ 2 = .00598 8
	24.918	56.0 – 111.4	110.034	1/110.2 = .009075
(12.6 / 246)	24.544	112.0		.01212 5 ÷ 2 = .006062
(6.5.2)	24.690	23.6 – 47.1	46.980	1/47.17 = .02120 .01214 ÷ 2 = .006070
(348)	25.010	56.3 – 111.0	110.194	1/1104 .009059
(12.2 / 55.2)	24.987	29.9	30.178	.02427 ÷ 4 = .006068
(35.2)	25.194	15.2 – 29.4	29.750	1/3000 .0333 .01218 ÷ 2 = .006090
(35.2)	25.162	47.4	47.176	1/47.27 = .02115

(2 | 54687) 24.89 common 24.91

10:52

$\frac{1}{24.91} = .04014 \times 1021$

$= v_1 = .04098$

$L_{og} = -2.6126$

$\frac{1}{2} n = -1.3063$

a

-10.4209 3.2256 -7.1953 -2.6126 -9.7395 log a -9.5934 -4.1595 log $\frac{n}{2}$ -1.7760 $\frac{n}{2}$ = 0.2640 $\frac{n}{a}$ = 1.5375 $1 - \frac{n}{a}$ = .5375

L_{og} .5375 = -1.9527 3.0566 -4.9093 4.9361 -1.9514

A = 4560

b = .006857

$v_1 + v_2 = .00625$ 16 → mean = 6058

$L_{og} = -3.7935$ -1.3063 3.1498 -6.2996 v = 1661

-4.8547 7556 -4.0988 -4.1567 -1.9427 e_1 = 11.80

-9.0720

$e^{\frac{n}{2}}$ -9.0720 / 2 = -4.5360 -1.1440 = $e^{\frac{n}{2}}$

.8752 $\frac{l}{a}$

-16.4209 3.2256 -4.6126 -14.2691 -3.7935 -12.4766 -4.1567 7554 -4.9121 3.0874

.000 1424 = a

1223 = $\frac{1}{\lambda a}$

Cond Aug 21 ST

.04014 .02715 1068292 .006129

4014 2333 12 | 7247 .006123

4014 4059 6 | 49199 .006150

4014 2170 6134 6 | 36258 .006043

4014 4075 4 | 49215 6152

4014 4014 2703 11 | 67117 .006101

4014 3105 6119 6129 6123 6150 6134 6152 6101 7 | 3208 6130

h 0 6 4

63) Monday Apr. 15, 1917 $\theta = 23.09$ $p = 62.70$ 56.74 5.98

Sixth Obs. at 11:07 PM.

11:02 P.M.

824.0
827.0
14.6
14.4
7680.0

824.5
822.0
14.6
14.7
1675.8

	G	F	
1	10.2 - 20.1	20.170	$\frac{1}{20.19} = .049525$
1523 / 2041	29.978 11.6 - 23.4	23.476	$\frac{1}{23.50} = .042553$
3042	30.258 14.3 - 28.0	27.784	$\frac{1}{27.80} = .035971$
1524 / 4566	30.092 17.6 - 34.6	34.400	$\frac{1}{34.43} = .029053$
1524 / 6090	30.112 32.2 - 64.8	64.658	$\frac{1}{64.502} = .015538$
1510 / 7600	30.124 32.4 - 65.2	65.132	$\frac{1}{65.25} = .029920$
	30.076 17.6 - 34.4	34.218	
	29.836		

$.020465 \div 3 = .006821$ $.013672 \div 2 = .006835$ $.013820 \div 2 = .006910$

Mean diff $= .006856$

11:25

$\frac{1}{29.1} = .03322 \times 1021$ $\nu_1 = .03322$ $\log = -2.5305$ $\frac{1}{2}n = -1.2653$

.03322 .04920 → .05272 .00636

.03322 .01538 → .04860 .00694

.03322 .02905 → .06227 .00691

.03322 .03537 → .06919 .00691

.03322 .04555 → .07877 .00691

$\nu_1 - \nu_2 = .00691 \times 1021 = .07062$

$\log = -3.8469$ -1.2653 3.1978_n -6.3120 3.2245 -9.0575 $V = .16775$

$e_1 = 12.23$

$c^{3/2}$

-9.0575_2

3 | -18.1750

-6.0583

$1144 \times 10^{-7} = e^2$

a	β
-16.4209	-4.8547
3.2345	.7767
-2.5305	-4.0780
-14.1759	-4.1090
-3.8469	-1.9690
3 -12.3291	.9310 = β/2
-4.1090	.0001295
.7767	
-4.8857	
3.11 43	1305. = 1/μ

ak

-10.46136
3.2345
-7.68586
-2.8469
$\log_{ak} = -5.83692$
-4.1090
$\log_k = -1.72794$
$\frac{1}{K} = .2720$
$K = 1.471$
$1 - \frac{1}{K} = .321$

$\log .321 = -1.9400$
3.1195
-4.8257

b = .0006695
-1.9400
-1.9690
-1.9712
$\beta = .9364$

No 65

(W) Tuesday, Apr. 16, 1912 — First Observation at 5:27 — θ = 20.00 — p = 6.56

Volts at 4:24 P.M.

836
836
13.1
13.1
1698.2

Three puffs were made since last nights reading and this observation was made after the second puff - Reading now is 6317 − 6321 = 6.96

Taking ½ of the diff - add to last nights reading gives 6.56 cm

G	F		
(15.6) 31.0		43.0	1/430 = .02326
(15.2) 30.8	30.4 − 60.0	60.0	
	30.0 − 60.1	60.1	1/6201 = .01667 = .01669
	30.0 − 59.6	59.937	.00696 ÷ 1 = .00696
31.282		42.494	
31.272		42.806	1/47.25 = .02367 = .023634
		43.300 = 1 division	.020754 ÷ 2 = .010918
31.210		59.686	1/3464 = .002886 = .002880
31.194		59.176	1/5931 = .01688 = .01693
31.438		59.070	.013943 ÷ 2 = .006997
31.194		26.460	1/26.5 = .03774 = .03770
31.214		26.546	.00710 ÷ 1 = .007100
31.286		22.296	1/22.30 = .04484
6|2090			mean 4 = .006961
31.261			
31 carried			
31.292			

5,55

1/31.29 = .03196 × 1021 = K₁

v₁ = .03263

log = −2.5136

½ v₁ = −1.2568

a	l
−16.42	−4.8547
3.2288	.6169
−2.5136	−4.0378
−14.1633	−4.1039
−3.8517	−1.9339
−13.3116	.8587 = l/a
−4.1039	.0001270 = a
.8169	
−4.9208	
+3.0792 = 1200 n₂ = 1/f₂	

1185 cent to bank

Any 21st ↗

.03196	.03196	.03196	.03196
.01664	.03634	3196	3196
7|.048860	8|.255947	288	1683
.006943	.006949	5|.034847	7|.048879
		.006968	.006970
		3196	6966
		3770	6968
		10|.06966	6949
		.006966	6943
			5|29.96
			1959

v₁ + v₂ = .006960 × 1021 = .007106

log = −3.8517 − 1.2568 = 2.1949 − 6.3063 = 3.2288 − 9.0785

e₁ = 11.95 — e₂ = 18.79 — e₃

−9.0785 − 2\|−18.1485 − 6.0479

111.7 = e³

No

Λ = 328/.8477 = 977 — log Λ = 2.9621 — n = 1.8948

b = 328/485 = .00659 — 1/n − 1 = .328 = 1/3.02

Very thankful for multiple observations very convincing. all times are corrected for drop

69

Tuesday Apr. 16, 1917 $\theta = 20.00$ $p = \frac{61.00}{58.72}$ 2.28

Second Observation at 6.45 Voltsat 6;45

834.0+
13.4
847.4

Voltsat 7.10

833.5+
13.9
857.4

G	F	X
7.904	10.194	
7.980	10.190	$\frac{1}{10.19} = .09814$
8.188		$\frac{.02860}{19} = .001505$
8.062	14.440	$\frac{1}{14.38} = .06954$
8.024	14.330	$\frac{.01340}{9} = .001469$
8.082	17.764	
8.066	17.970	$\frac{1}{17.895} = .05604$
7.994	17.786	$\frac{.01358}{9} = .001509$
8.060	23.598	$\frac{1}{23.55} = .04246$
8.110	23.518	$\frac{.01080}{9} = .001529$
8.094	23.530	
8.170	31.492	$\frac{1}{31.465} = .03176$
8.080	31.438	$\frac{.023827}{16} = .001489$
8.022	125.794	$= .007937$ $\frac{.004512}{3} = .001504$
8.08	80.180	$= .012468$ $\frac{.00295}{2} = .001485$
7.994	64.804	$\frac{1}{80.18} = .01540$
8.078	46.976	$\frac{1}{64.8} = .02160$ $\frac{.00586}{4} = .001465$
8.052	47.284	$\frac{1}{46.98} = .02128$
0.98		
2.16		
113689		
8052		

$\frac{1}{8052} = .03242 \times 1021 = .1268$

v. correction $= .1269$

$\log = -1.1035$

$\frac{1}{2} = -.6551$

a	
-16.4209	-4.8547
2.9306	.3579
-1.1035	-4.4968
-14.1550	-4.4968
-3.1624	.0726
3|-11.2726	$1182 = \frac{1}{a}$
-4.4292	$= .1166$
3579	.000656
-47821	
3.2179	$1652 = \frac{1}{a}$
	$1630 = \frac{1}{ka}$

$4\|19.9972$
$= 7.9979$
99.34^{12}

66) Tuesday Apr. 16, 1912
Third Observation at 8:45

θ = 20.30 p = 6143 − 5620 = 523

Volts at 8:45 830.0+
14.2
844.2

Volts at 9:25 827.5+
14.2
841.7

G	F	fall
50.842	34.358	
	49.920	
51.164	50.662	
	16.934	
51.776	16.962	
	52.516	
50.890	51.542	
51.682		
18.630		
51.44		

Balanced Speed

1/3236 = .03159 corr = .03186 → .01202/2 = .06010
1/50.29 = .01988 corr = .01984 → .03916 → .01958
1/1695 = .05900 corr → .03982/2 = .01991
1/52.03 = .01922 corr = .1918 → .01918
.01948 mean

Diffs		
01940	1940	1940
1978	5900	1989
03858	7840	3924
01929	01960	01962
		480
01940		1924
		1940
		4 1191
		1948

1/51.44 = .01944
corr = .01940 × 1021 = .01981 = V₁

V₁V₂ = .01948 × 1021 = 5.01989

Log = −2.2969
1/2 = −1.1484

9:23

Log = −2.2986
−1.1484
3.1963
−6.6453
2.9253
−9.7200
5249
67
V = 842

e₁ = 51.88

a	l
−16.4209	−4.8547
2.9253	5092
−2.2969	−4.3455
−15.6431	−5.7815
−2.2986	.5640
3 13.3445	3.664 = 1/a
−5.7815	= .3620 corr to table
5892	.0000596
−4.2907	
3.7093	

5120 1/pa
50
5070 = 1/pa corr to table
.5070

e^{2/3}
1-19.7151
2
3)-17.4302
-6.4767
2997 × 10⁻³ = e^{2/3}

No. 69

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5014	6100	
5041	6106	
5056	6109	
5065	6120	
5069	6125	
5098	6109	
5120	6115	
5145	6120	
5166	6111	
5168	6101	
5190	6116	
	61.111	

Determination of A & K

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Final value of e

$e_0^{3/2} = e_1^{3/2} - d\,\tau_{max} = \left(e_1^{3/2} - d\,\frac{79.m - 61.1^{s}}{467.5}\right)^{x} = \left(e_1^{3/2} - d \times .03820 \times 10^{-5}\right)^{x}$

1	d = 8856	$e^{3/2} = 6440$	$e_1 = 5.168$	$\tau_{mid} = 1.9972$		6440	$e^{3/2}$ =	6.101
2	d = 5401	$e_1^{3/2} = 6308$	$e_1 = 5.010$	$\tau_{mid} = 7325$		3396		
				4736		61.00N		
				3183	2078	6308		6.101
						2078		
						61.009		
3	d = 5991	6335	5041	7775	6335			6.106
				5335	2798			
				3693	61057			
4	d = 74.64	6400	5.120	8759	6400			6.115
				5335	2802			
				4567	61.136			
5	47.90	6293	4.991	6603	6293			6.110
				5338	2892			
				2641	61.098			
6	71.40	63.82	5.098	8537	6382			6.109
				5338	2738			
				4375	61.062			
7	89.23	64.59	5.190	9505	6459			6.115
				5338	3022			
				5343	61.168			
8	6068	63.57	5.069	7881	6357			6.125
				5335	2797			
				3061	61.143			
9	5609	63.24	5.028	7487	6324			6.109
				5335	2788			
				2372	61.084			
10	60.92	63.33	5.040	7847	6333			6.100
				5335	2836			
				3885	60994			
11	48.28	62.82	4.981	6837	6282			6.098
				5335	2691			
				2675	60.989			
12	61.19	63.54	5.065	7667	6354			6.120
				5335	2347			
				3295	61.108			
13	8507	64.36	5.166	9396	6436			6.111
				5335	2953			
				5136	61.103			
14	65.44	63.20	5.012	7438	6321			6.098
				5335	2786			
				3276	60.974			
15	44.75	62.75	4.971	6536	6275			6.104
				5335	2718			
				2341	61.034			
16	6159	63.45	5.056	7895	6347			6.109
				5335	2362			
				3338	61.088			
17	4671	62.52	4.979	6604	6252			6.103
				5335	1791			
				2582	61.029			
18	4944	62.13	5.017	6901	6213			6.124
				5335	1896			
				2789	61.234			
19	4609	63.00	5.001	6636	6300			6.124
				5335	1768			
				2474	61.192			
20	51.65	62.13	5.016	7130	6213			6.116
				5335	1990			
				2966	61.150			
21	8078	62.32	4.982	6105	6232			6.126
				5335	1304			
				1083	61.258			
22	7826	64.19	5.145	8933	6419			6.120
				5335	3008			
				4793	61.189			

$e_0^{3/2} = 61.11$

$e_0 = 4.777$

American Physicists

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Irving Langmuir Schenectady N.Y.
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A P Carman ··NWAB

Density of Clock Oil

Taken by R.A. Millikan April 5/12

Weight of empty bottle = 10.9181
" " Bottle full = 20.1586
" " " + water = 20.9338

∴ " of oil alone = .9235
∴ " " water " = 10.0157

Relative density = .9221

Abs density of oil = .9221 × .9976 = .9199

Temperature of both oil and water = 23°

$$e_n = \frac{v_1}{v_2}\left(\frac{9\eta}{2}\right)^{\frac{3}{2}} \frac{1}{g(\sigma-\rho)} \frac{d(v_1+v_2)v_1^{\frac{1}{2}}}{PD} = \frac{4\pi}{3}\left(\frac{9\cdot 1825}{2}\right)^{\frac{3}{2}} \frac{1}{980.3(9199-\rho)}^{\frac{1}{2}} 1.6\,\frac{(v_1+v_2)v_1^{\frac{1}{2}}}{PD}$$

$$= \frac{\pi \times 6.4 \times (.00582125)^{\frac{3}{2}}}{(980.3 \times .91873)^{\frac{1}{2}}} \times 100 \times \frac{(v_1+v_2)v_1^{\frac{1}{2}}}{PD \text{ volts}}$$

$$= \frac{\pi \cdot 640 \times (.00582125)^{\frac{3}{2}}}{(980.3 \times .9187)^{\frac{1}{2}}} \frac{(v_1+v_2)v_1^{\frac{1}{2}}}{PD \text{ volts}}$$

Calc of constant coef of $\frac{(v_1+v_2)v_1^{\frac{1}{2}}}{PD}$

Log 640 = 2.80618
" $(\ )^{\frac{3}{2}}$ = −5.371714
−2.67504
+1.47728
−3.19776

Log π = .49715
" 980.3 = 2.99136
" .9187 = −1.96319
2 | 2.95455
1.47728

Log 1.9 = .26103
∴ " = .13051
5
.39154

Log (1) + 89.94734
= 10.94734
−5.371714

Thus $e = \frac{mg}{F}\left(\frac{v_1+v_2}{v_1}\right)$

Calc of $\frac{v_1}{v_2}$ $\quad \frac{v_1}{v_2} = \frac{mg}{Fe-mg}$ $\quad \therefore e = \frac{mg}{F}\frac{v_1+v_2}{v_1}$

$e_1 = \frac{2}{9}\pi a^2(\sigma-\rho)\frac{g}{F}\left(\frac{v_1+v_2}{v_1}\right)$ $\quad \therefore a^2 = \frac{3Fe}{4\pi g(\sigma-\rho)}\frac{v_1}{(v_1+v_2)}$

$a^3 = \frac{3e}{4\pi g\Delta 3\cdot(\sigma-\rho)}$ $\quad \frac{v_1 PD_{\text{volts}}}{v_1+v_2} = \frac{4777}{4\pi\cdot 100\cdot .9195}\frac{v_1 PD}{v_1+v_2}$

log e = −10.67916	.60206 = log 4
6.25824	.49715 = " π
−16.42092	2.99136 = " 3
	2.30412 = " 1/2
	−1.96355 = " 9195
	6.25824

∴ $a = 1.636 \times 10^{-4}$ cm

Thus is just 1% smaller than value yielded in calcs which means that a must be reduced 1%

Calc of a_k $\quad e = \frac{6\pi a_k \mu v_2}{F}$ $\quad \frac{v_1}{v_2} = \frac{e}{e-mg}$ $\quad \frac{v_1+v_2}{v_2} = \frac{e}{e-mg}$

$\therefore a_k = \frac{eF}{6\pi\mu(v_1+v_2)}$ $\quad$ but $F = \frac{PD}{300d}$

$\therefore a_k = \left(\frac{PD}{v_1+v_2}\right)\frac{e}{300d\,6\pi\mu_{23}}$

$\therefore a_k = \log^{-1}(-0.46136) \frac{PD}{v_1+v_2}\{1-\beta\cdot\ldots$

Calibration of Hipp Chronometer

30 sec interval		20 sec interval	10 sec. interval	16 sec. Int.	Duplicate 20 sec.
14981	14995	9979	5003	.8012	9976
14994	14979	9996	4980	.7980	9996
14991	14960	9987	4992	.8003	10014
14993	14986	9962	5011	.8013	10002
14965	14986	9981	4995	.8015	10006
14982	14986	9999	4996	.8005	10023
15001	15003	10012	5014	.8011	9994
14970	14964	9983	4990	.8001	10008
14999	15007	9972	5019	.8005	9977
14965	14963	9983	5007	.7996	10005
9836	14967	9964	50009	.0041	100001
14.9836	14.986	918	50009	.80041	100.001
29.9672	29.972	9.98345	10.0018	1.60082	20.0001
Corr=.1%		19.96690	Corr=0	Corr=0	
		Corr=.069.			

6 sec.	40 sec.	60 sec	112 sec.	
3001	19991	29969	111.864	-.13
3031	19985	29950		
3037	19984	29962	116. sec	
3008	19955	29939	115.722	-.24%
2995	19984	29948		
3017	19950	149768		
3002	19960	29953.6	120. sec	
2980	19954	59.9072	119.782	-.19%
2989	19996			
2988	19959		+.20%	
3026	9718			
3013	19.9718			
36188	399436			
3007.33				
6.0146	+.15%			
-.25%				

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