A REDETERMINATION OF THE DIELECTRIC CONSTANT OF BENZENE

by

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A. B. College of Emporia, 1928.

Submitted to the Department of Physics and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Arts.

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August 1929.

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INTRODUCTION

During the past thirty or thirty-five years, considerable interest has been taken in the problem of dielectrics. The dialetric constants of various materials have been measured, and the effects of various conditions investigated.

Benzene is a liquid which is purified with comparative ease. It has a rather low dielectric constant in the neighborhood of 2.28 at ordinary temperatures. It has high insulating properties, making it suitable for measurements. Numerous observers have attempted to measure the dielectric constant of benzene, and have obtained values ranging from 2.23 to 3.8[11.*] at room temperatures. However, the high values have been obtained with very high frequencies, and if we limit our values to those obtained with frequencies below 5 x 10^8 cycles per second, most of the values lie in the neighborhood of 2.28 at about 25° C., and in view of the difficulty of handling very high frequencies we may feel safe in eliminating those values.

Considering the supposed accuracy of the experimental proceedure in a number of cases we find surprising variation in the results obtained. For example, a determination by a bridge method[1.] using 1000 cycles in 1925, gave a value of 2.2482 ± .0003 at 25° C.

*Numbers refer to Bibliography.

Another set of observers, using a resonance scheme, and a frequency of about 10^6 cycles per second, obtained a value of 2.2389 ± .0005 at 25°. However, this value was given to show the consistancy of the method used, and was not supposed to have absolute value. A third set of observers using a beat note method, and a frequency of 10^6 cycles per second, obtained a constant of 2.282 ± .003 at 25°C. We see that the values disagree far beyond the estimated errors.

Below, I have inserted a table of values obtained by previous observers, taken from a recent article.[11.]

Previous Determinations of the Dielectric Constant and Temperature Coefficient of Benzene.

Temp. °C.	Air = 1	$\frac{d\epsilon}{dt}$	20°C Vacuum=1	Frequency	Authority	Date
18	2.235	-0.0020	2.231	1500	Neinst	1894
--	------	-0.0015	------	Audio	Ratz	1896
19	2.26	- ----	2.26	4×10^8	Drude	1897
18	2.288	-0.0016	2.285	5000	Turner	1900
--	------	-0.0019_2	------	Audio	Tangl	1903
17	2.287	- ----	2.282	4×10^8	Colley	1910
15	2.288	-0.0015	2.276	6×10^5	Isnardi	1922
30	2.260	-----				
14.8	2.291	-----	2.282	800	Waibel	1923
20	2.276	-0.0019	2.277	10^6	Graffunder	1923
21.8	2.23_9	0.0015_3	2.24_3	10^6	Meyer	1924
20	2.28_5	0.0015_2	2.28_6	10^6	Grutsmacker	1924
20	2.270	0.0018_5	2.271	Audio	Lange	1925
25	2.24_7	-------	2.25_8	1000	Harris H.	1925
15	$2.291_{5\pm5}$	$9.0019_{8\pm3}$	$2.282_{5\pm5}$	1000	Hartshorn and Oliver	1928

Additional values taken from another[1] source are listed below.

Temp. °C	ϵ	Method	Frequency	Observer
17	2.27	bridge	audio	Veley
10	2.29	bridge	radio	Errera
--	2.25	resonance	radio	Klein
16	2.24	bridge	audio	Philips
--	2.28	bridge	audio	King & Patrick
25.5	2.2402	resonance	10^6	Sayce & Briscoe

It is very evident that there are difficulties either in measurements or purification, or in both.

Several methods have been developed but three have been in general use during the last few years.

One of these is the bridge scheme. The bridge consists of two arms containing capacities, one of which is the standard or standard and unknown combined. The other two arms may be either resistances or capacities, or a combination of both. An audio frequence source of current is used, and a telephone detecting device is used in balancing the bridge. It is balanced both with the test condenser in and out of the circuit, and the capacity obtained from the change necessary in the standard condenser to compensate for the test condenser.

There are several prerequisites for successful operation of the bridge. The supply must be a pure sine wave* in order that a definite balance may be obtained. Also currents in the arms of the bridge must be in phase at all times. Capacity between different portions of the bridge must be eliminated by shielding.

*Fleming. Proc. Royal Soc. (2) 23:117 1911.

Also capacities between portions of the bridge and the source of supply, ground, etc. cause trouble.

Since the introduction of the three electrode tube, two other methods capable of considerable accuracy have come into use. One of these is a method of setting the standard condenser by tuning for a zero beat note between two high frequency oscillators, or by producing a zero beat with an audio note and the beat between two oscillators, the other is a system of setting the condenser by resonance.

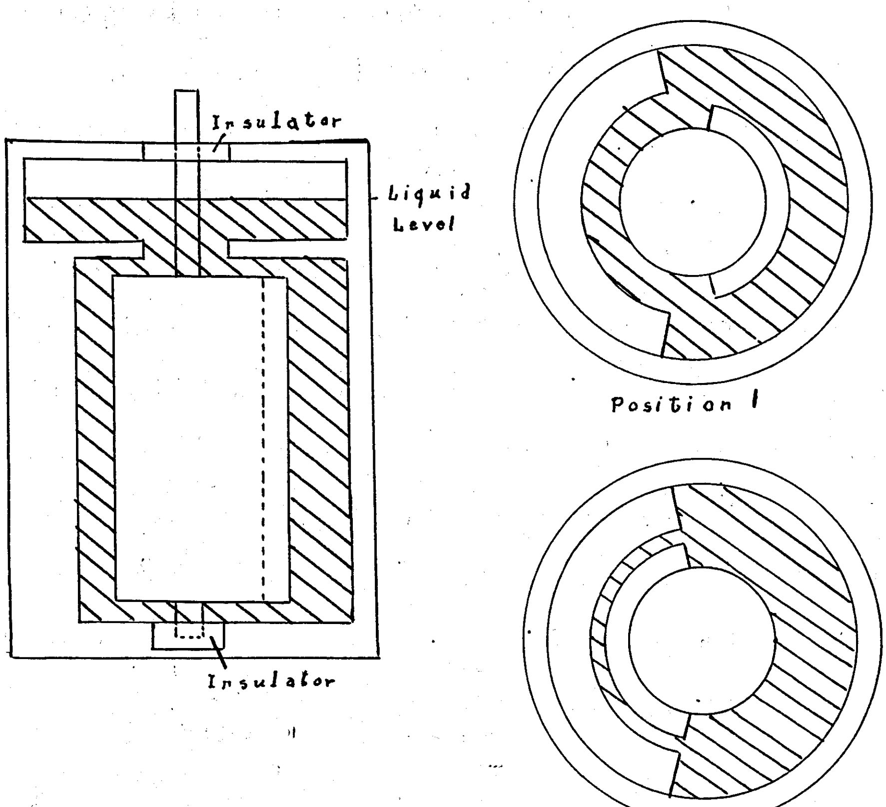
With careful construction, apparatus using either of these methods is capable of an accuracy one part in a thousand or more, depending upon conditions.

In obtaining the dielectric constant of a liquid it is customary to measure the capacity of a condenser first with a vacuum (or usually air) as dielectric, then with the liquid ad dielectric. In order that the ratio of capacities be the true dielectric constant, the air capacity must be located entirely in the liquid, and the two must be geometrically identical. Leads to the test condenser have capacity which does not fulfill the stated requirements. Also solid insulation used for spacers adds errors which are not the same for air and for the liquid capacity. Strays of various sorts enter into the measurements, and make additional work necessary. Several methods are used to eliminate these errors.

II. Apparatus

The test condenser used in the experimental work was of a type described by R. Darbord,[12] and made possible the complete elimination of all undesirable capacities without additional measurements being introduced. The condenser had an eccentric rotar and stator, enclosed, so that strays and lead capacities would not change due to movement of the rotar. All moving parts outside this enclosure were concentric, so that no capacity changes were introduced.

Test Condenser (Schematic diagram)



Position 1

Position 2

Fig 1

Let C_1 be the desired air cap in pos. 1. (Fig. 1).

Let C_2 be all strays, etc., in air pos. 1.

Let C_3 be the desired air cap in pos. 2.

C_2 is unchanged by rotation so the capacity change upon turning the rotar 180° is

$$\text{Capacity } C = (C_3 + C_2) - (C_1 + C_2) = C_3 - C_1.$$

Similarly let --

C_1^1 be desired liquid cap in pos. 1.

C_2' be all strays, etc., in pos. 1.

C_3' be desired liquid capacity in pos. 2.

C_2' is unchanged as before.

Then the capacity change is

$$C^1 = (C_3^1 + C_2^1) - (C_1^1 + C_4^1) = C_3^1 - C_1^1$$

But $C_1^1/C_1 = \epsilon$ also $C_3^1/C_3 = \epsilon$

where ϵ is the dielectric constant.

Now let C_3^1 be n time C_1^1. Then C_3 is n time C_1 for $\frac{C_3^1}{C_3} = \frac{C_1^1}{C_1} = \frac{nC_3}{C_3} = n$ so $C_3^1 - C_1^1 = (n-1)C_1$

and similarly $C_3 - C_1 = (n-1)C_1$

$$\text{so } \frac{C_3^1 - C_1^1}{C_3 - C_1} = \frac{(n-1)C_1^1}{(n-1)C_1} = \frac{C_1^1}{C_1} = \epsilon$$

So the ratio of the change of capacities of the liquid and air capacities upon rotation of the condenser through the same angle in each case is the true dielectric constant.

The test condenser was built in the shop of the Department of Physics, University of Kansas, of brass tubing and plate, with glass insulated bearings.

Four concentric brass tubes were used, the outer and the inner tubes forming the basis of the stator and rotor respectively. Portions of the other two tubes forming slightly less than one-half a cylinder, having an arc of about 160°, were soldered to the stator and rotor tubes, forming eccentric walls. When these eccentric walls were adjacent, the spacing was less than 0.1 cm. and the capacity was much larger than when the rotor was turned to a position 180° from that.

The bottom of the condenser was of a moderately thick brass plate with a conical hole in the center of the inner surface. This hole and the eccentric surface of the stator were turned at the same time so that they were accurately centered with respect to each other.

The lower bearing was a glass rod ground hemispherical on one end, and set into a brass plate. One side of the plate had a conical extention (see diagram Fig.) to fit the conical hole in the base. Three bolts held the plate to the bottom and allowed slight adjustment of the bearing.

The ends of the rotor were of brass plate. The shaft of the rotor had a conical hole to fit on the lower bearing. This hole and the eccentric surface were turned at one time to provide accurate centering of the whole rotor.

A circular brass plate, with a central hole, and tapered toward the center on the lower side to allow bubbles to escape, was bolted to the upper end of the eccentric stator plate. Three bolts led from this through the top, which was then secured by wing nuts.

The top was a circular plate fitting snugly in the rotar case. Three extensions held the surface even with the top of the stator tube. The upper bearing was clamped to the top by bolts and wing nuts.

The upper bearing was a three point support one of which consisted of a steel rod adjusted by means of a spring, giving a very accurate bearing. This was clamped between glass plates giving a good bearing which was insulated. Rectangular glass plates with a central hole were used. A brass plate with a similar hole and two bolts on the end (see Fig. 3) held the bearing tightly on the lower surface of the top.

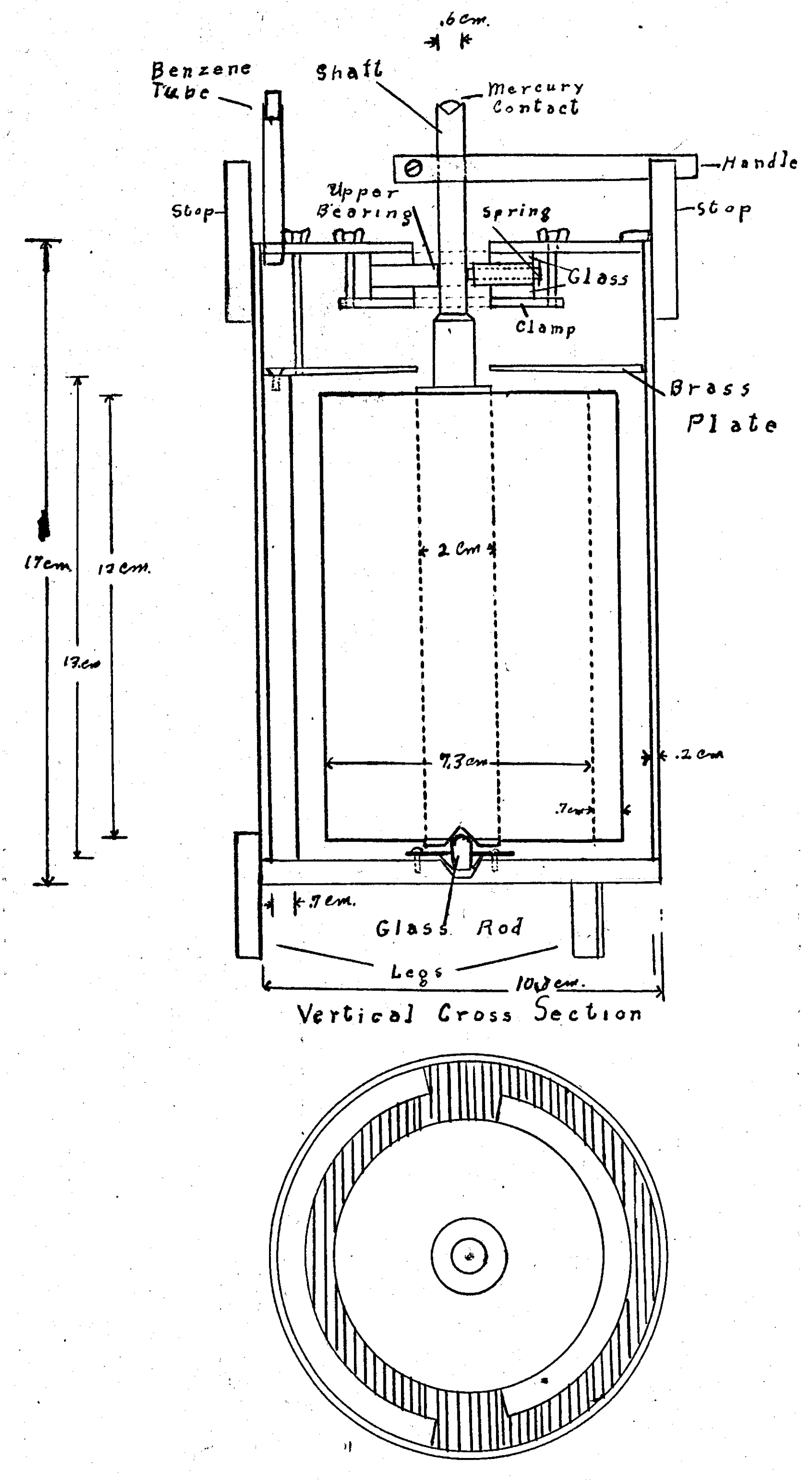
A hard rubber handle was clamped to the end of the rotar shaft. Stops allowed a rotation of 180°.

Three brass legs were soldered to the stator, giving a stable support.

A brass tube screwed through the top allowed the benzene to be admitted without leaving large air holes.

A cork ring was fitted over the shaft and slipped against the upper bearing to close the holes around the three point support.

Test Condenser



Vertical Cross Section

Horizontal Cross Section

Fig 2

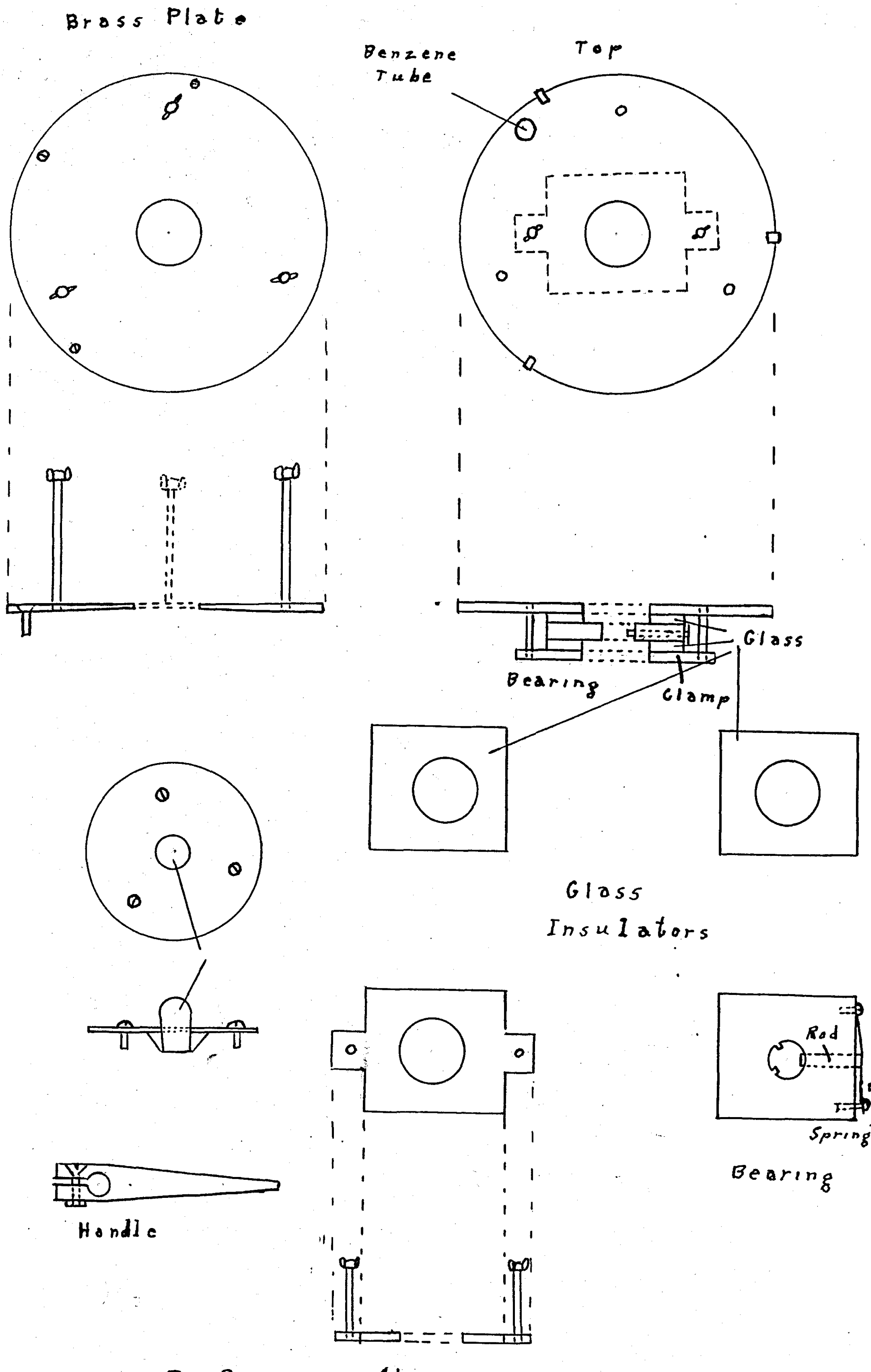

Brass Plate
Benzene Tube
Top
Glass
Bearing
Clamp
Glass Insulators
Rod
Spring
Bearing
Handle
Clamp

Fig 3

The beat note apparatus consisted of a crystal control oscillator of .569 Kilo cycles in one shield, an oscillator in another shield tuned by condensers, and a detector and two stage amplifiers in a shield located between the oscillators.

Beat Note Apparatus.

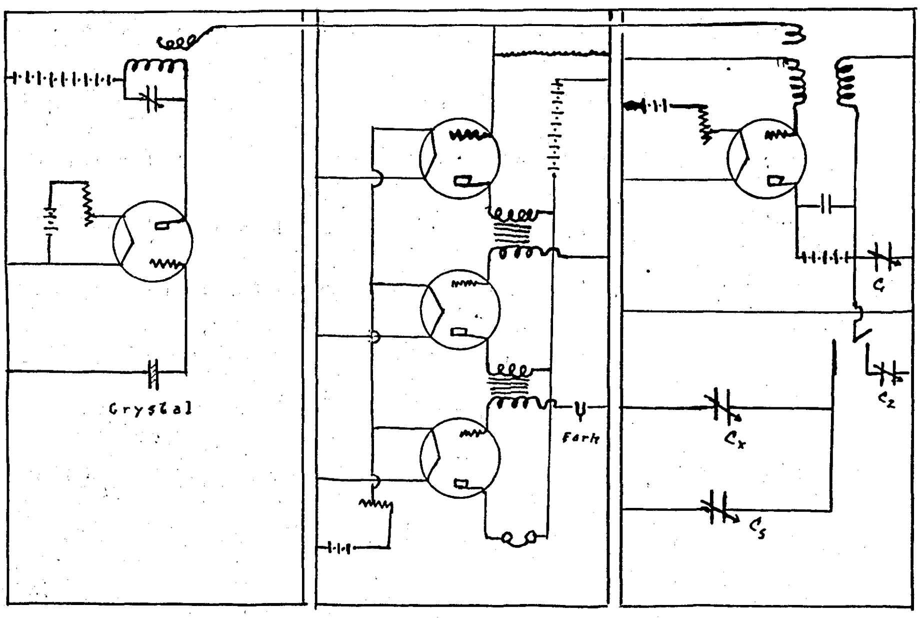


Fig 4

C_x - Test Cond.
C_s - Standard
C_1 - Midget
C_2 - Comparison

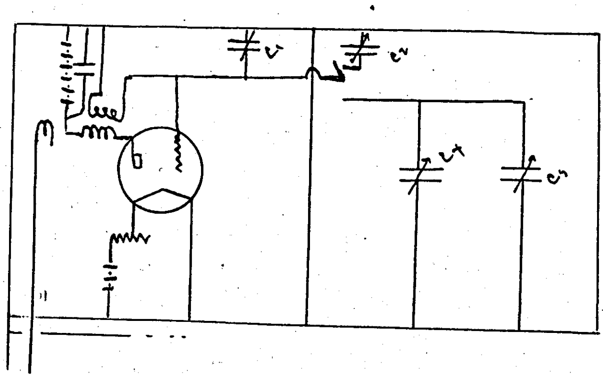
A wire fastened to the grid of the detector led into either shield, and three turns inside the coils picked up enough energy to work the detector, but did not couple the oscillators appreciably. The oscillator was tuned to produce a zero beat with a thousand cycle electrically driven fork in the grid return of the last audio tube. C. was a midget condenser connected permanently to the oscillator.

C_2 was a variable which was left unchanged during a test. The standard could be compared with it by throwing the switch, and any drift of frequency could be compensated for by C_1.

It was necessary to allow the oscillator to run for some time until it became stable. Aotherwise the frequency would drift so fast as to make readings unreliable. Discharging the storage battery through a six ohm resistance aided in obtaining a stable condition.

Later the circuit was changed to the one shown below, giving much more stable operation, and eliminating much of the trouble due to drift.

Fig 5



C_x represents the test condenser. C_1 - Midget

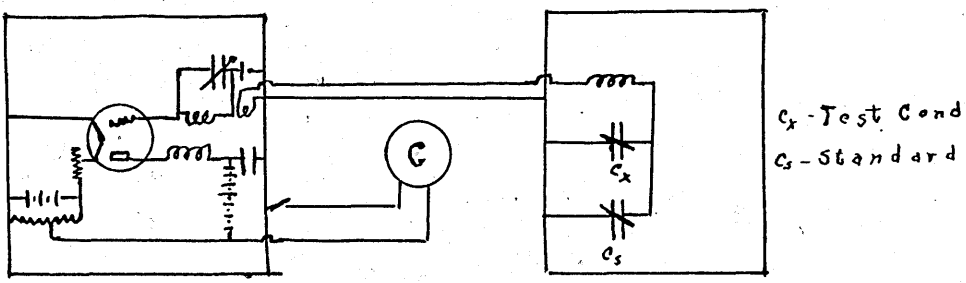
C_5 represents the standard condenser. C_2 - Comparison

The resonance apparatus was of a type described by Sayce and Briscoe[2.] and used in their work.

An oscillator of the conventional type in a shidd contained a galvanometer in the negative B lead. The ground and grid return were connected to the negative A lead. A potentiometer was connected across the A battery and the slider was connected through a resistance to the positive side of the galvanometer, allowing the plate current to be balanced out of the galvanometer. This allowed the use of a very sensitive galvanometer and gave a very sensitive method of detecting changes in the plate current.

A second shield held the test and standard condensers and an inductance. In series with the inductance was a three turn coil in the oscillator box placed about one inch from the ground end of the oscillator inductance, to couple the two circuits. It was found that the closer coupling was necessary, as the increased change in plate current more than overcame the decrease in sharpness of the resonance peak. The coupling used was the loosest that could be used while still retaining the full accuracy of the condenser setting.

Resonance Apparatus.



The frequency was about 750 kilo cycles. A plate potential of 22.5 voltes and a C potential of 1.5 volts, with a 201 A tube for oscillator gave a plate current of approximately .002 amps., or about 1000 times that for full scale deflection of the galvanometer. At the lower end of the grid potential plate current curve was used the plate current dropped as the standard condenser was tuned for resonance. It was found necessary to use a thirty ohm rheostat in series with the potentiometer, to hold the galvanometer on the scale.

The standard was set by observing the point of greatest deflection on the galvanometer. It was possible to reset within .06 $\mu.\mu.$f. and over a period of thirty or forty minutes the variation was only .20 to .30 $\mu.\mu.$f.

The standard condenser used was a worm driven Precision Condenser type, 222, built by the General Radio Co. It could be read to .06 $\mu.$ $\mu.$ f. and was calibrated in the beat note oscillator, with the aid of another condenser of the same type, so that the capacity is known within about .06 $\mu.\mu.$f. at any point.

All readings were taken at 25°C or within two or three degrees of room temperature at all times. A thermostat was therefore unnecessary, and the temperature of the condenser was regulated by a water bath regulated by hand. A glass container with thick walls was fitted with a wooden cover which fitted around the top of the test condenser leaving only the top itself exposed to the air. A stirrer, heating coil, and thermometer were immersed in the bath. The thermomemter was standardized by comparison with a thermometer calibrated by the Bureau of Standards. It could be read to hundredths of a degree. It was found possible to hold the temperature within less than .1° C at all times and usually within .03°C.

III. Proceedure.

There was available chemically pure benzene. Most of the readings were made on this benzene.

The particular benzene used was Mallinckrodt's Reagent Quality Benzol. The chemical analysis was as follows:

Carbon Disulfide	0.0025%
Non Volatile Matter	0.0025%
Thiophene	0.0000%
Other Organic Impurities	None

Consequently the usual purifying process was deemed unnecessary.

Freshly cut sodium was carefully washed and placed in the benzene, and allowed to remain for two or more days. Then the benzene was distilled and measured immediately.

Two attempts were made to purify commercial benzene by the same process as used by other observers. Benzene was shaken for some time with successive portions of pure concentrated sulphuric acid, until the latter portions were only slightly colored. Then it was washed with distilled water, sodium hydroxide and more water. It was dried partially with calcium chloride, decanted and distilled. The remaining portion was fractionally crystallized three times, dried in the usual manner with sodium and distilled. Tests with mercury, and lead acetate gave no indication of sulphur compounds.

When measurements were made the water bath was filled, the test condenser put in position, and the temperature regulated. Several minutes were allowed for the condenser to reach an even temperature. Then the change of capacity was measured as the test condenser rotor was changed from maximum to minimum capacity positions. Then the benzene was distilled, and run immediately from the container through glass tubing in a two hole cork stopper, into the test condenser. The rotor was set at minimum capacity to give sufficient spacing to prevent bubbles remaining in the benzene. Also the condenser was carefully tilted a few degrees in various directions to aid bubbles in escaping from the lower chamber.

Capacity measurements were made with a General Radio Precision Condenser, type 222. The condenser can be read to approximately .06 micro-micro-farods. It was calibrated by use of the beat note oscillator and a similar condenser, so that the capacity of a reading is known to about the accuracy with which it may be taken.

Number One.

C. P. benzene (New sample) beat note osc.

Air

Reading	Capacity	Reading	Capacity	Temp. °C.
1110.2	660.47	1692.0	1012.41	
1110.1	660.41	1692.0	"	
1110.1	"	1692.0	"	
1110.1	"	1692.0	"	
1110.1	"	1692.0	"	

Capacity change 352.00

Benzene

234.2	134.54	1564.6	934.36	
234.2	".	1564.8	935.48	
234.3	134.60	1564.8	"	
234.3	"	1564.8	"	
234.4	134.66	1564.9	934.54	

Capacity change 800.88

$\epsilon = 2.2752.$

Number Two.

C. P. benzene (new sample) beat note.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1243.8	741.34	1689.4	1010.86	25.00
1243.9	741.40	1689.5	1010.92	
1244.6	741.46	1689.6	1010.98	
1244.1	741.52	1689.6	1010.98	

Capacity change 269.40

<u>Benzene</u> 22.5 volts on oscillator.

533.6	313.26	1549.5	926.27	25.00
533.7	313.32	1549.6	926.33	
533.9	313.44	1549.6	926.33	25.00
534.0	313.50	1549.9	926.51	

Capacity change 612.98

$\epsilon = 2.2754$

<u>Benzene</u> 45 volts on oscillator.

498.3	291.86	1514.8	905.02	25.00
498.3	291.86	1514.8	905.02	
498.4	291.92	1514.9	905.08	
498.4	291.92	1514.9	904.08	

Capacity change 613.16

$\epsilon = 2.2760$

Number Three.

C.P. benzene (No. 2 redistilled) beat note.

Air

Reading	Capacity	Reading	Capacity	Temp. °C.
1118.6	665.77	1562.6	934.12	25.00
1118.6	665.77	1562.7	934.18	
1118.6	665.77	1562.7	934.18	
1118.6	665.77	1562.8	934.24	
1118.7	665.83	1562.8	934.24	
		Capacity change	268.41	

Benzene 22.5 volts on oscillator.

417.1	243.32	1431.1	854.45	
417.2	243.38	1431.2	854.51	25.10
417.3	243.44	1431.3	854.57	
417.3	243.44	1431.3	854.57	
		Capacity change	611.13	

ϵ =2.2768

Benzene 45 volts on oscillator.

381.1	221.66	1395.7	832.86	
381.2	221.72	1395.8	832.92	25.05
381.3	221.78	1395.9	932.98	
		Capacity change	611.29	

ϵ = 2.2771.

Number Four

C. P. Benzene (New sample)

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.°C
1627.6	973.42	1187.1	706.96	25.00
1627.4	973.30	1187.0	706.90	
1627.3	973.24	1186.9	706.84	
1627.3	957.24	1186.9	706.84	

Capacity change 266.40

<u>Benzene</u> 22.5 volts on oscillator.

1502.1	897.20	496.1	290.54	25.00
1502.1	897.20	496.1	290.54	
1502.0	837.14	496.0	290.48	

Capacity change 606.66

1517.5	906.65	512.4	300.33	25.00
1517.6	906.71	512.4	300.33	
1517.6	906.71	512.4	300.33	

Capacity change 606.38

Average change 606.52

ϵ = 2.2766

<u>Benzene</u> 45 volts on oscillator.

1486.0	887.53	479.9	280.94	25.00
1436.0	827.55	480.0	281.00	
1486.0	887.53	480.0	381.00	25.00
1486.0	837.53	480.0	281.00	

Capacity change 606.53

ϵ = 2.2766.

Number Five

C. P. benzene (No. 3 redistilled) beat note.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp. °C
1620.2	968.93	1181.9	703.88	24.98
1620.2	968.93	1182.0	703.94	25.00
1620.3	968.99	1182.1	703.94	
1620.2	968.93	1182.0	703.94	

Capacity change 264.99

<u>Benzene</u>

Reading	Capacity	Reading	Capacity	Temp. °C
1492.2	891.28	492.3	288.32	
1492.2	891.28	492.3	288.32	25.03
1492.2	891.28	492.2	288.26	
1492.3	891.34	492.4	288.38	

Capacity change 269.96

ϵ = 2.2754

<u>Benzene</u> 45 volts on oscillator.

Reading	Capacity	Reading	Capacity	Temp. °C
1459.6	871.82	495.4	268.82	25.04
1459.6	871.82	459.6	268.94	
1459.6	871.82	459.4	268.82	
1459.6	871.82	459.6	268.94	25.06

Capacity change 602.94

ϵ = 2.2753

Number Six.

C. P. benzene (No. 4 Redistilled) beat note.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1548.6	925.72	1108.3	659.38	25.00
1548.6	925.72	1108.4	659.44	
1548.7	925.78	1108.4	659.44	
1548.7	925.78	1108.4	659.44	
1548.7	925.78	1108.5	659.50	

Capacity change 266.31

<u>Benzene</u> 22.5 volts on oscillator.

1407.8	840.18	401.5	233.78	25.02
1408.0	840.30	401.7	233.90	
1408.0	840.30	401.7	233.90	25.04

Capacity change 606.40

ϵ = 2.2770

<u>Benzene</u> 45 volts on oscillator.

1386.9	827.60	380.5	221.37	
1386.9	827.60	380.4	221.31	25.03
1386.9	827.60	380.4	221.31	

Capacity change 606.27

ϵ = 2.2765

Number Seven

C. P. benzene (No. 5 redistilled) beat note.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1529.4	913.92	1084.0	644.73	24.98
1529.5	913.98	1084.1	644.79	
1529.5	913.98	1084.2	644.85	25.00
1529.6	914.04	1084.2	644.85	

Capacity change 269.18

<u>Benzene</u> 22.5 volts on oscillator.

1405.0	838.48	387.4	225.44	25.00
1405.0	838.48	387.6	225.50	
1405.0	838.48	387.5	225.44	
1405.0	838.48	387.5	225.44	

Capacity change 613.02

$\epsilon = 2.2771$

<u>Benzene</u> 45 volts on oscillator.

1397.1	833.71	379.6	220.76	
1397.1	833.71	379.6	220.76	
1397.2	833.77	379.8	220.88	25.02
1397.2	833.77	379.7	220.82	

Capacity change 612.95

$\epsilon = 2.2769$

Number Eight

C. P. benzene (No. 6 redistilled) beat note.

Air

Reading	Capacity	Reading	Capacity	Temp.
1445.0	862.99	998.5	593.31	
1445.0	862.99	998.5	593.31	25.02
1445.1	863.05	998.5	593.31	
1445.1	863.05	998.5	593.31	

Capacity change 269.71

Benzene

1341.4	800.31	322.5	186.61
1341.4	800.31	322.6	186.67
1341.6	800.43	322.7	186.73
1341.7	800.49	322.8	186.79
1341.8	800.55	322.9	168.85

Capacity change 613.70

$\epsilon = 2.2754$

Number Nine

Commercial (purified) beat note

Air

Reading	Capacity	Reading	Capacity
1536.1	918.04	1090.5	648.59
1536.1	918.04	1090.6	648.65
1536.1	918.04	1090.6	648.65
1536.1	918.04	1090.6	648.65
1536.1	918.04	1090.7	648.71
		Capacity change	269.39

Benzene

1409.9	841.51	381.4	221.84
1409.9	841.51	381.4	221.84
1409.9	841.51	381.3	221.78
1409.9	841.51	381.3	221.78
		Capacity change	619.70

ϵ = 2.296

Number Ten

Commercial (No. 9 redistilled) beat note.

Air

Reading	Capacity	Reading	Capacity	Temp.
1736.7	1039.85	1284.8	765.92	25.00
1736.7	1039.85	1284.7	765.86	
1736.7	1039.85	1284.7	765.86	
1736.7	1039.85	1284.7	765.86	

Capacity change 273.93

Benzene

1610.3	962.68	571.5	336.05
1610.3	962.68	571.5	336.05
1610.2	962.62	571.5	336.05

Capacity change 262.61

$\epsilon = 2.287$

Number Eleven

Commercial (No. 10 redistilled.) Resonance.

Air

Reading	Capacity	Reading	Capacity	Temp. °C
1736.8	1039.91	1292.3	770.65	
1736.7	1039.85	1292.2	770.59	
1736.7	1039.85	1292.2	770.59	
1736.8	1039.91	1292.2	770.59	

Capacity change 269.27

Benzene

1612.8	964.10	591.4	347.89
1612.7	964.04	591.4	347.89
1612.7	964.04	591.2	347.77
1612.6	963.98	591.3	347.83

Capacity change 616.21

ϵ = 2.290

Number Twelve

Commercial (Number 11 redistilled) beat note.
resonance.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1535.1	917.43	1080.7	642.86	
1535.1	917.43	1080.7	642.86	
1535.1	917.43	1080.8	642.92	
1535.2	917.49	1080.8	642.92	
1535.2	917.49	1080.8	641.92	

Capacity change 274.57

<u>Benzene</u> beat note.

1411.2	842.17	364.5	211.82
1411.2	842.17	364.6	211.86
1411.2	842.17	364.6	211.86

Capacity change 630.33

ϵ = 2.293

<u>Benzene</u> resonance.

1612.0	963.71	567.8	333.88
1612.0	963.71	567.9	333.94
1612.0	986.71	567.9	353.94
1612.0	963.71	567.9	333.94

Capacity change 629.77

ϵ = 2.294

Number Thirteen

C. P. benzene (No. 8 redistilled) resonance.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1736.3	1039.61	1288.9	768.40	
1736.4	1039.67	1288.9	768.40	
1736.3	1039.61	1288.9	768.40	

Capacity change 271.23

<u>Benzene</u>

1611.0	963.10	585.2	344.23	
1610.9	963.04	585.3	344.29	
1611.0	963.10	585.4	344.35	
		585.3	344.29	

Capacity change 618.77

ϵ = 2.2811

Number Fourteen

C. P. benzene (No. 13 purified) resonance beat note.

Air

Reading	Capacity	Reading	Capacity	Temp.
1535.6	917.73	1082.4	643.88	
1535.6	917.73	1082.5	643.94	
1535.7	917.79	1082.6	644.00	
1535.7	917.79	1082.7	644.06	
1535.8	917.85	1082.6	644.00	

Diff. 273.80

Benzene — beat note.

1411.8	842.53	369.5	214.82
1411.8	842.53	369.5	214.82
1411.8	842.53	369.5	214.82

Capacity change 627.71

ϵ = 2.292

Benzene — resonance.

1612.0	963.71	571.9	336.34
1612.1	963.77	571.9	336.34
1612.1	963.77	571.9	336.34

Capacity change 627.41

ϵ = 2.291

Number Fifteen

C. P. benzene (No. 14 redistilled) resonance.

<u>Air</u>

Reading	Capacity	Reading	Capacity	Temp.
1727.5	1034.19	1273.0	758.92	25.00
1727.4	1034.13	1272.9	758.86	
1727.4	1034.13	1272.9	758.86	
		1272.9	758.86	

Capacity change 275.27

<u>Benzene</u>

1602.7	958.12	559.8	329.13	24.96
1602.6	958.06	559.8	329.13	
1602.6	958.06	559.8	329.13	25.00

Capacity change 628.95

ϵ = 2.285

Results

Sample	Beat note 22.5 volt	Beat note 45 volt	Resonance
1. C. P.		2.2752	
2. "	2.2754	2.2760	
3. "	2.2768	2.2771	
4. "	2.2766	2.2766	
5. "	2.2754	2.2753	
6. "	2.2770	2.2765	
7. "	2.2771	2.2769	
8. "		2.2754	
9. Commercial		2.296	
10. "		2.287	
11. "			2.290
12. "		2.296	2.294
13. C. P.			2.2811
14. "		2.292	2.291
15. "			2.285

For the C. P. 45 volts (1-8)* mean deviation 0.00065

probable deviation from mean 0.00025

For the C. P. 22.5 volts (2-7) mean deviation 0.0007

probable deviation from mean 0.0003

V. Discussion.

The temperature coefficient of benzene as given by numerous workers is too small to be noticeable here, as the changes would be below the limit of accuracy of the readings. The air capacity was usually around 240 $\mu\mu$.f. with an accuracy of .06 $\mu\mu$.f. in reading at each end, and also with a possible error of the same size due to calibration. So the maximum error could be about 0.24 $\mu\mu$.f. or about one part in a thousand or .002 in the constant. It is seen that the maximum variation is of that order.

Tests with varying intensity of the applied potential, showed no effect which could not be attributed to errors. Variations were made by changing the plate potential in the beat note oscillator. In the resonance apparatus, the intensity was much less, as the applied potential came from the energy picked up by the three turn coupling coil, from the oscillator.

I should judge that the variations obtained in later work with the C.P. benzene were due partly to a mistake in mixing samples. I do not understand the cause of all the variations, however. The values of the commercial benzene varied in a similar manner to those for the C.P., indicating that the C.P. and commercial may have been mixed by accident.

It may be that the purification process is lacking in some point. I believe that more investigation might be valuable.

Considering the results obtained by others and myself, I believe that an estimated error is of no value. But I believe that this method has several advantages over other methods, and further use and investigation would be profitable.