Dielectric Strength Notes
Note 4

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Impulse Breakdown of Deionized Water

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Table I shows the results of five investigations of the breakdown strength of water.

In (1), the large area plates of a water Blumlein generator are broken by applying voltage waveforms of identical shape but different amplitude, and the peak or breaking voltage, V, measured, together with time, t, for which the voltage is greater than 63% of this value. (The voltage does not reverse). Graph I shows a plot of the resulting points, which shows a clear time dependence expressible as $Ft^{1/3} = 0.15$ (the slope of the line drawn is actually - 0.3). The standard deviation of $Ft^{1/3}$ is only 7%, which is significantly lower than the 12% typical for analogous numbers obtained when breaking down polythene or oil.

In experiment (2) a smaller test electrode system is broken down repeatedly at three different spacings. Such factors as the conductivity of the water or its freedom from dissolved gas and suspended dust are found to be completely unimportant. The breakdown field is constant for all three electrode separations; no significance should be attached to the fact that the highest field occurs for a slightly shorter time. The field and time varied in the many firings, mean values are quoted, and no dependence of F on t can be deduced from the individual results, though it is possible scatter could mask such an effect. $Ft^{1/3}$ is again calculated.

Experiment (3) uses a somewhat larger, intermediate area, and a much larger gap. Fields are lower than in (2), times longer, $Ft^{1/3}$ is intermediate between (1) and (2). No more deductions can be made owing to the paucity of the data.

Experiment (4) is of less interest; the area quoted for this ball gap is that stressed to 90% of the maximum field.

In Experiment (5) an area somewhat smaller than that in (2) is subjected to much shorter pulses; the results, ignoring the variation of gap, appear in Graph II, where it seems that $Ft^{1/2}$ = constant would be a better fit. Nevertheless $Ft^{1/3}$ is calculated in the table, since it turns out to have the same value as approximately the same area gave in (2) when stressed for times in order of magnitude.

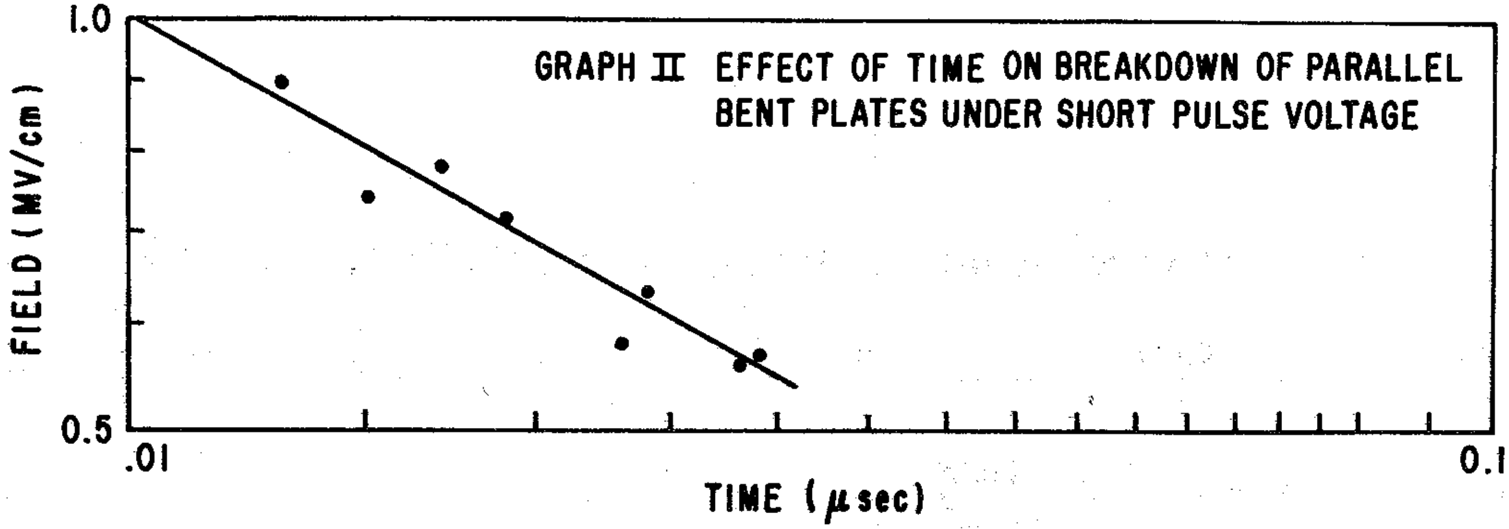
The longer data in (1) - (5) can be interpreted as indicating that $Ft^{1/3}$ = constant, independent of gap d. The constant depends only on the area, and this variation is shown in Graph III. It corresponds to a slope only two thirds of that proposed for polythene and oil, and this may correspond to the smaller standard deviations observed in some cases.

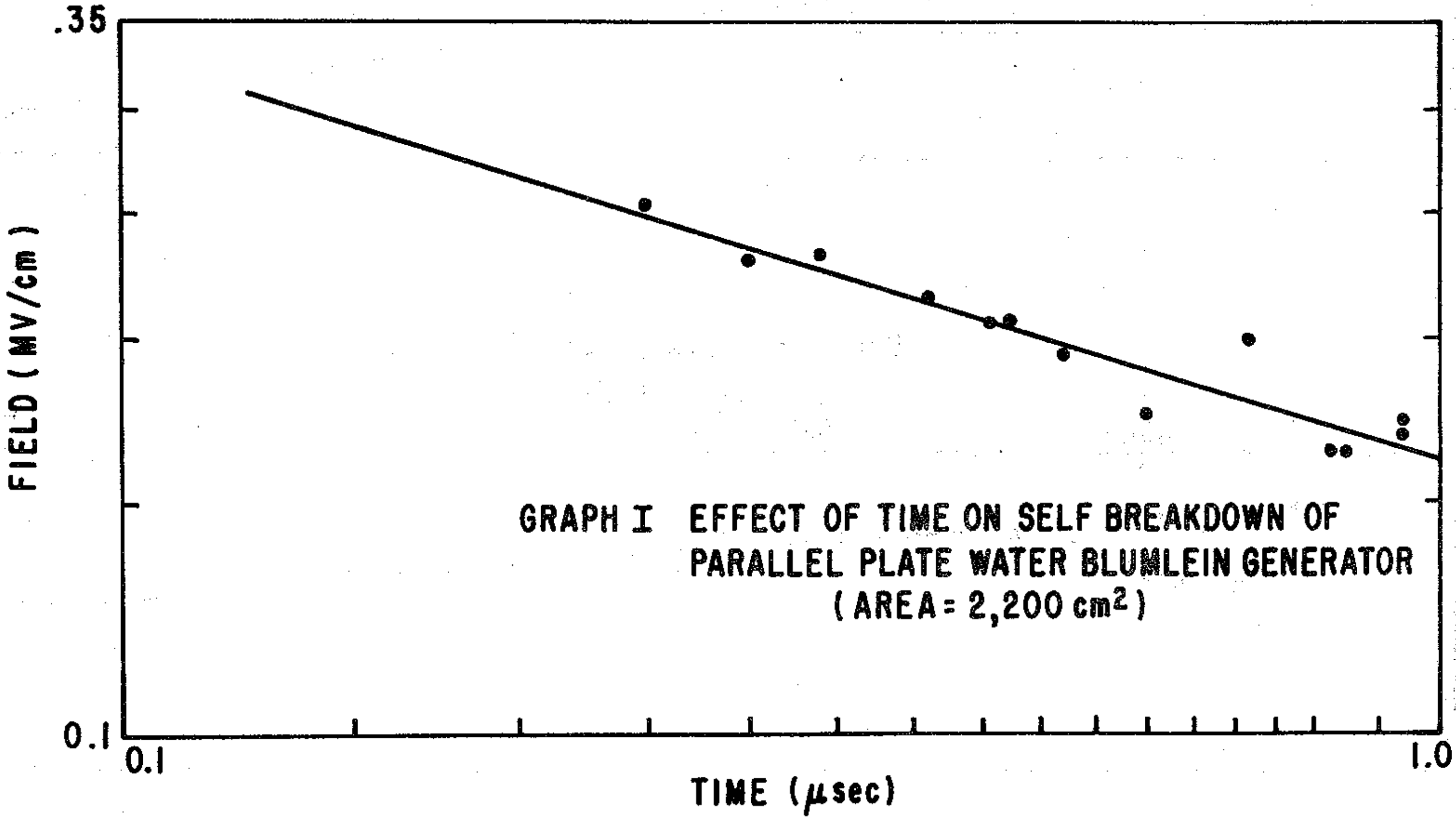
An entirely different interpretation is based on the fact that there is reason to believe that a relationship $d^2 = 50\ Vt$ or $Ft/d = .02$ previously obtained for point-point and point-plane gaps should be carried over in some form to plane-plane gaps. In the case of points, the discharge is assumed to start instantly and the formula describes a pure transit phenomenon, but in the plane case a finite threshold field would appear. Thus in (2) the threshold may be about 0.3 MV/cm, since the data indicates the transit time is short. In the ball bearing case (4) it would be even shorter, so the threshold must be about .8 MV/cm, while in (1) it can be at most .17 MV/cm. Here the transit time is now becoming significant and it should be dominant in (3), where the gap is large and the threshold must still be about .20 MV/cm. Thus (4) does not support this theory, and it is here in (3), the region of large gaps and voltages, that the second interpretation makes water seem very attractive as an energy storage medium, and where the interpretations begin to disagree. Further work will be done in this to try to decide this issue; the truth may well lie in between, of course. Graph IV shows the effect of area on the threshold proposed.

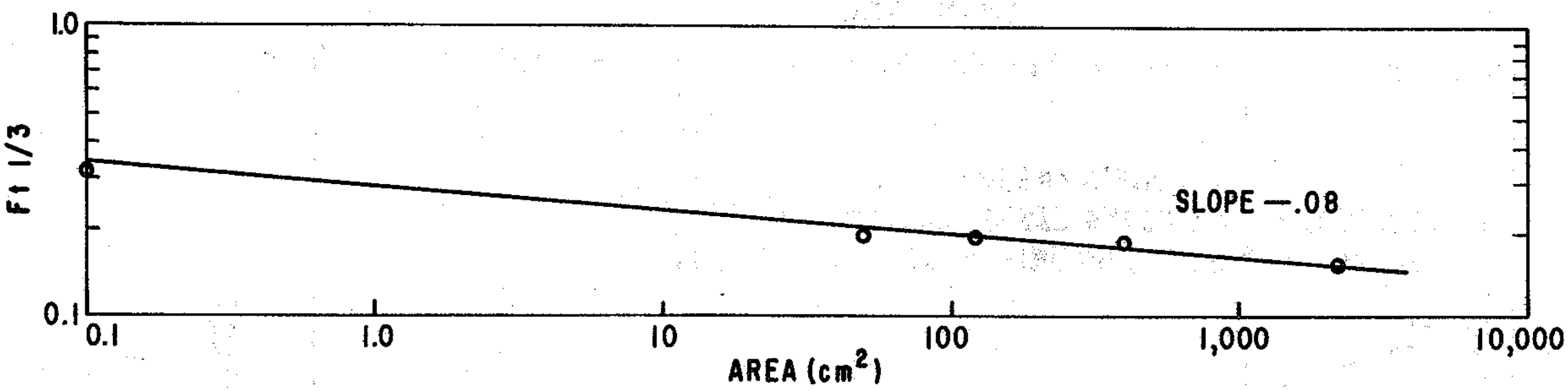
For completeness mention must be made of data to be found in Soviet Physics Technical Physics Vol. 9, No. 6 (Dec. 1964) for ball gaps less than 1 mm. This region seems rather remote from ours, but it is of interest that the data is consistent with $Ft^{1/3}$ = a constant; this is shown on Graph V, where the data is tabulated.

TABLE I

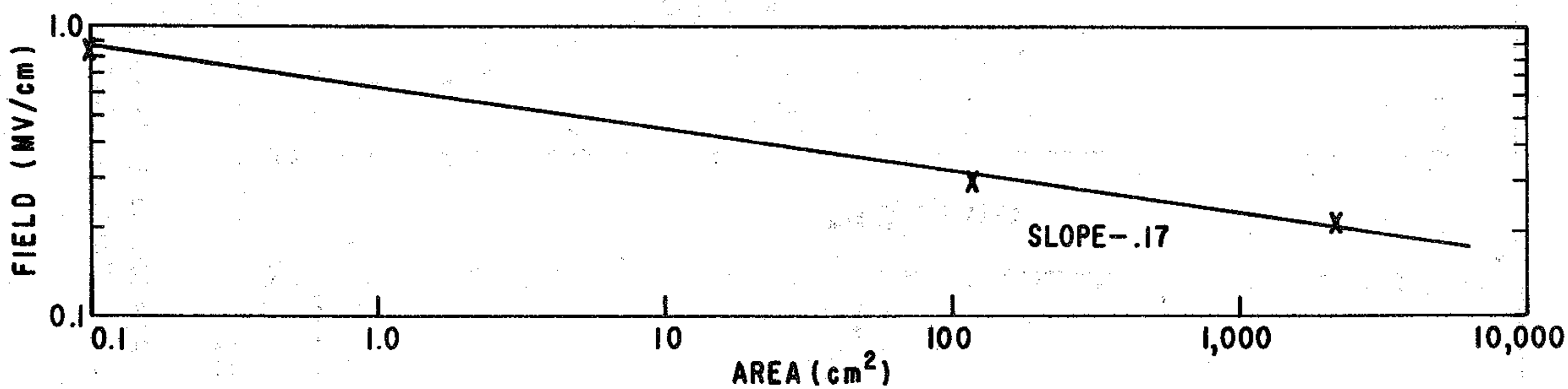
	d cms.	V MV	F MV/cm	t µsec	A cm	$Ft^{1/3}$	
	1.5	.297	.198	.52	2200	.16	
	"	.258	.172	.94	"	.17	
	"	.258	.172	.94	"	.17	
	"	.248	.165	.83	"	.15	
	"	.245	.163	>.96	"	-	Each line 1 firing of
	"	.310	.207	.47	"	.16	parallel plates of
	"	.300	.200	.74	"	.18	Blumlein generator
(1)	"	.325	.216	.41	"	.16	
	"	.296	.198	.28	"	.13	
	"	.350	.233	.34	"	.16	
	"	.263	.175	.60	"	.14	
	"	.248	.165	.85	"	.15	
	"	.395	.253	.25	"	.16	
	"	.345	.230	.30	"	.15	
	"	.310	.207	.46	"	.16	
						TAKE 0.15; Standard deviation ~7%	
	.63	(.22	.35	.19	120	.20)	(8) Firings of
(2)	.96	(.30	.31	.23	120	.18)	Means of (13) parallel
	1.26	(.39	.31	.23	120	.19)	(12) test plates
	3.6	.81	.22	.3	400	.17	Each line 1 firing
(3)	4.6	1.1	.24	.37	400	.21	of parallel test
	4.6	1.16	.25	.55	400	.15	plates
						Mean 0.18	
	0.18	.145	.77	.05	0.1	.28	Each line 1 firing
(4)	0.18	.17	.95	.05	0.1	.35	of ball bearing
	0.18	.18	1.0	.04	0.1	.34	gap
						Mean 0.32	
	.35	.32	0.9	.013	50	.22	
	.47	.33	.74	.015	50	.18	
	.45	.35	.78	.017	50	.20	Each line 1 firing
	.63	.45	.71	.019	50	.19	of parallel plates on
(5)	.63	.38	.58	.023	50	.17	fast pulse generator
	.63	.41	.64	.024	50	.19	
	.63	.37	.57	.029	50	.17	
	.80	.45	.56	.028	50	.18	
						Mean .193	


GRAPH II EFFECT OF TIME ON BREAKDOWN OF PARALLEL BENT PLATES UNDER SHORT PULSE VOLTAGE
FIELD (MV/cm)
1.0
0.5
.01
0.1
TIME (μsec)


GRAPH I EFFECT OF TIME ON SELF BREAKDOWN OF PARALLEL PLATE WATER BLUMLEIN GENERATOR (AREA = 2,200 cm²)
FIELD (MV/cm)
.35
0.1
0.1
1.0
TIME (μsec)

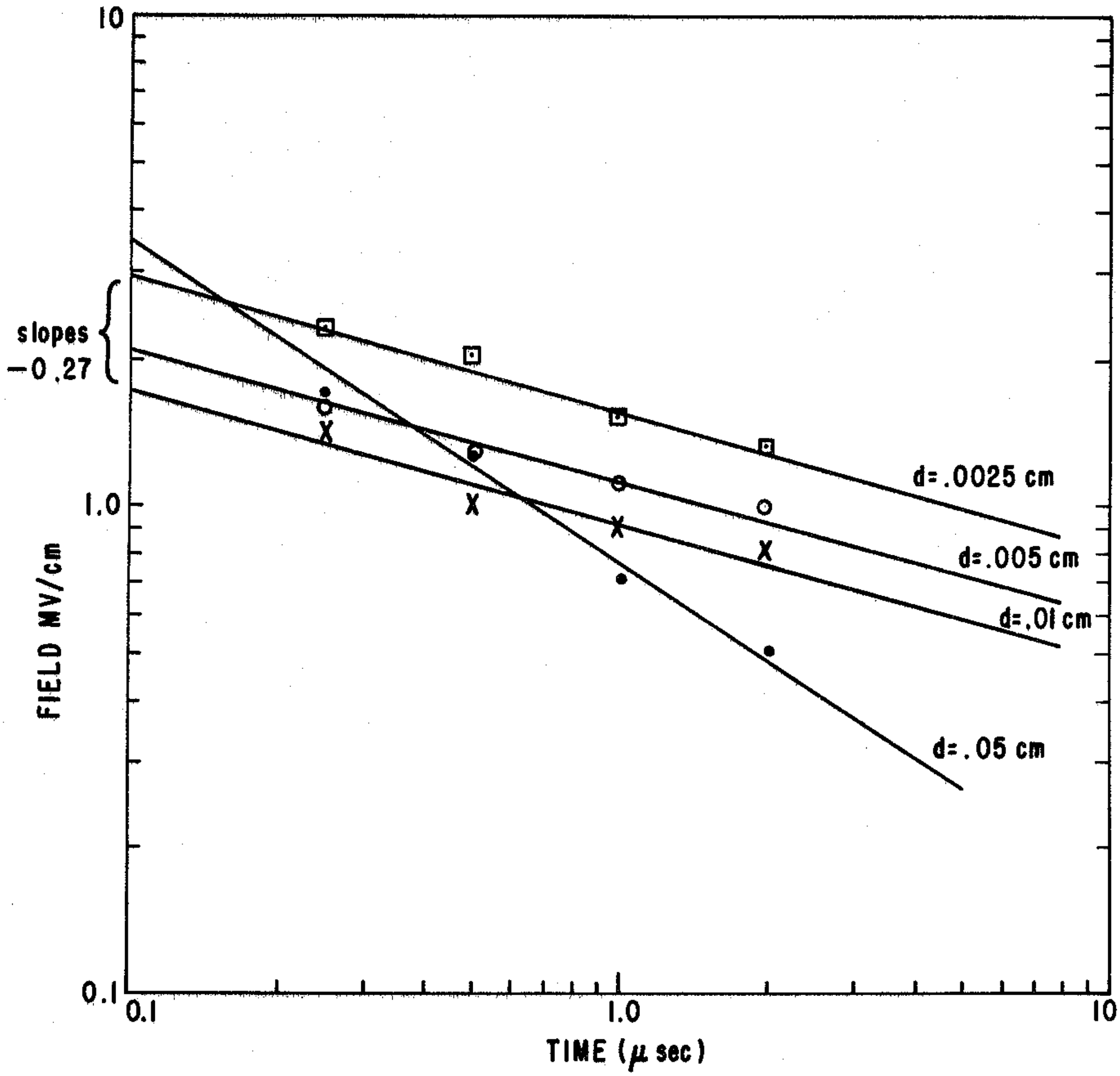


GRAPH III AREA EFFECT FOR Ft 1/3



GRAPH IV AREA EFFECT FOR THRESHOLD FIELD (VERY APPROXIMATE)

d cm	.05	.05	.05	.05	.01	.01	.01	.01	.005	.005	.005	.005	.0025	.0025	.0025	.0025
t μsec	.25	.5	1.0	2.0	.25	.5	1.0	2.0	.25	.5	1.0	2.0	.25	.5	1.0	2.0
F MV/cm	1.7	1.3	.7	.5	1.6	1.0	.9	.8	1.6	1.3	1.1	1.0	2.3	2.0	1.5	1.3
A (cm^2)	.01				.002				.001				.0006			



GRAPH V RUSSIAN DATA FOR SMALL BALL GAPS. (SOVIET PHYSICS. TECHNICAL PHYSICS) VOL 9 No.6 (DEC 1964)