Dielectric Strength Notes
Note 10

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Velocity of Propagation of High Voltage Streamers in Several Liquids

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These experiments were carried out using a pulse transformer producing voltages up to one million volts rising in ≈ 0.5 μsecs., and the "Dagwood" 1.3 million volt Blumlein generator with a pulse length of ≈ 45 nanosecs. The test electrodes consisted of a 2" ball bearing and a sewing needle. The fine needle tip was to minimise any threshold field effects.

Measurements were made of the needle to ball gap over a range of 3 - 30 mms, peak voltage, and the effective time measured as that for which the voltage is greater than 63% of its maximum. Data was obtained for transformer oil, carbon tetrachloride, glycerine and deionized water.

The results for the first three suggest that the mean velocity $\bar{v} = d/t_{eff} \propto V^n$ (applied voltage) where n lies between 1.2 and 1.8, except for the positive streamers in glycerine which are much less dependent on voltage $n = 0.55$.

The effective time of 63% to peak is the calculated time for an equivalent square pulse of peak amplitude as derived from the relationship $\bar{v} \propto \bar{v}^{3/2}$ and the generator's waveforms. The timing errors introduced by the variation of n are small.

The case of water is an exception: according to Mr. Martin's original positive streamer formulae one expects this to be the case, since

$$\frac{dx}{dt} \propto \frac{V}{x} \quad \text{of} \quad \bar{v}t^{1/2} = kV^{1/2}$$

The results obtained are in close agreement with this, giving $\bar{v}t^{1/2} = 8.8\ V^{0.6}$.

Results for the negative water streamers suggest $\bar{v}t^{1/3} = kV$ as being the best fit for the data obtained.

The water (and the positive glycerine streamers) are also physically different from the others, being more bushy as compared with the spidery nature of the oil, carbon tetrachloride and negative glycerine streamers.

Graphs 1-8 show the plotted results which have been obtained by two operators using different monitoring systems over a large period of time, making it difficult to estimate the accuracy of V, t, and x. Analysis of the results give the following coefficients of correlation and standard errors of the constants K and n.

		r
Oil, positive	$\bar{v} = (90 \pm 12)\ V^{1.75 \pm 0.12}$	0.96
" negative	$\bar{v} = (31 \pm 5.5)\ V^{1.28 \pm 0.15}$	0.95
Carbon tetrachloride, positive	$\bar{v} = (168 \pm 28)\ V^{1.63 \pm 0.15}$	0.97
" " negative	$\bar{v} = (166 \pm 29)\ V^{1.71 \pm 0.19}$	0.95

		r
Glycerine, positive	$\bar{v} = (41 \pm 1.5)\, V^{0.55 \pm 0.03}$	0.98
" , negative	$v = (51 \pm 8)\, V^{1.25 \pm 0.13}$	0.98
Water, positive	$\bar{v}t^{1/2} = (8.8 \pm 0.4)\, V^{0.6 \pm 0.03}$	0.97
" , negative	$\bar{v}t^{1/3} = (16 \pm 0.25)\, V^{1.09 \pm 0.02}$	0.99

$\bar{v}$ is measured in cms/μsec.
V " " " megavolts
t " " " microsecs.

An approximate calculation based on the oil positive streamer formulae predicts that for a pair of parallel plates with a small projection on the positive plate $\bar{F}t^{0.59}$ = constant and independent of separation, $\bar{F}$ being the mean field V/d .

For a given area of plates, investigations have shown that $\bar{F}t^{1/2}d^{-1/4} = K$ is a better estimate, being only slightly dependent on d.

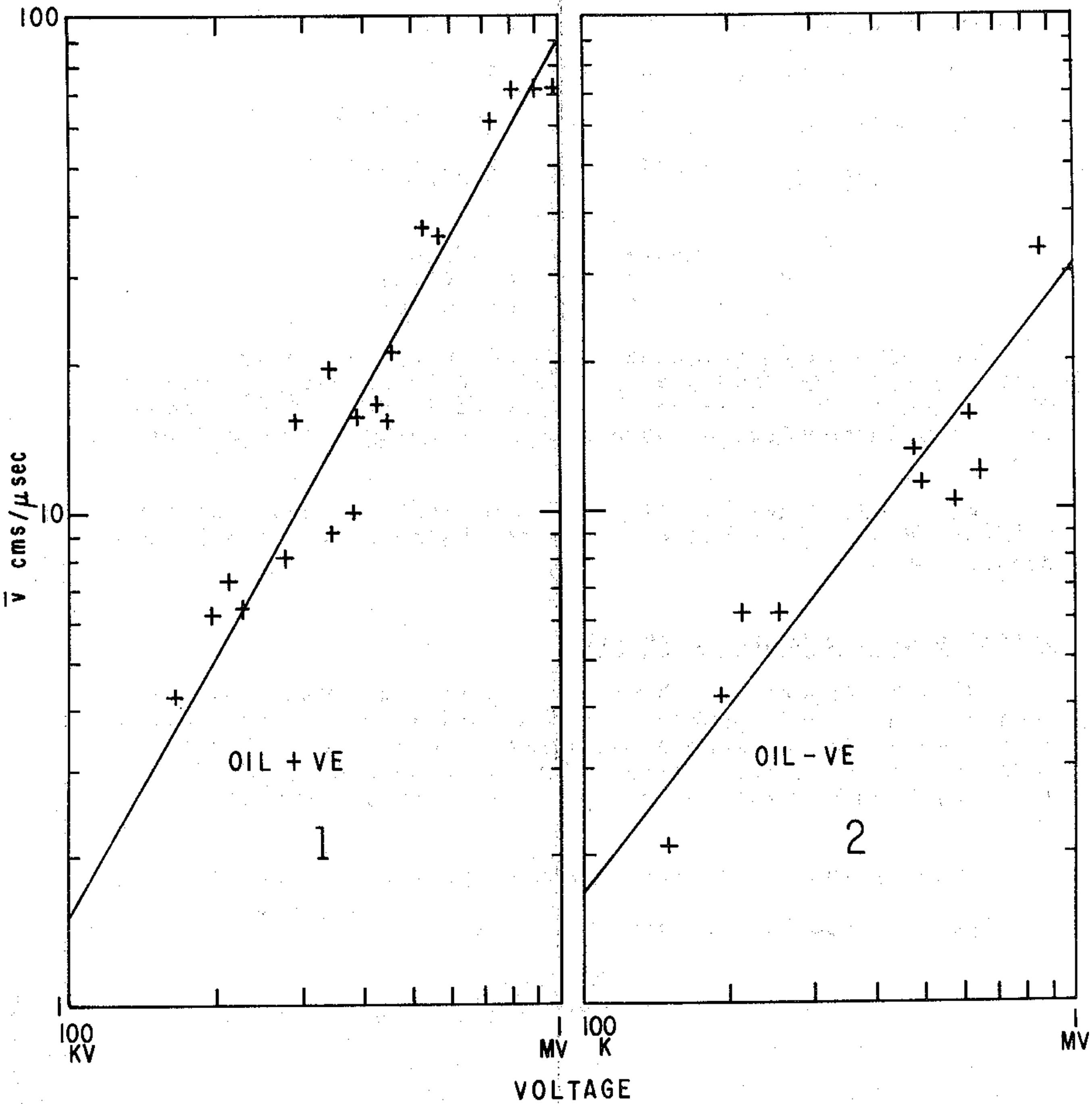
Velocity of streamers in polythene.

Similar experiments have been carried out with polythene. Sewing needles were pushed into 3/4" and 1" polythene sheets, with needle tip to plane separations ranging from 6-13 mms. Care was taken to avoid errors due to threshold field effects since with such small volumes polythene has a strength > 5 MV/cm.

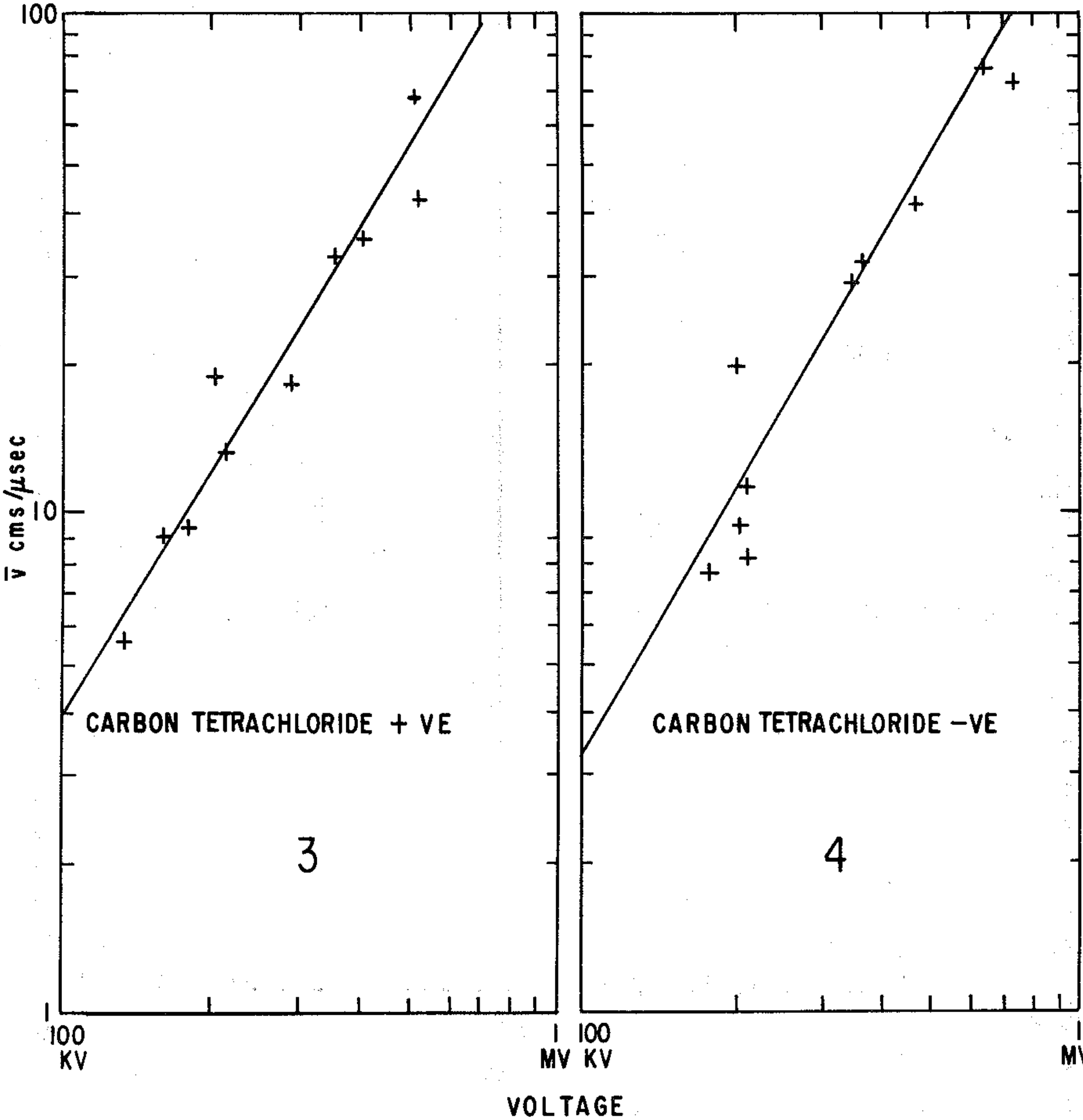
Graph 9 shows the data obtained and analysis gives:

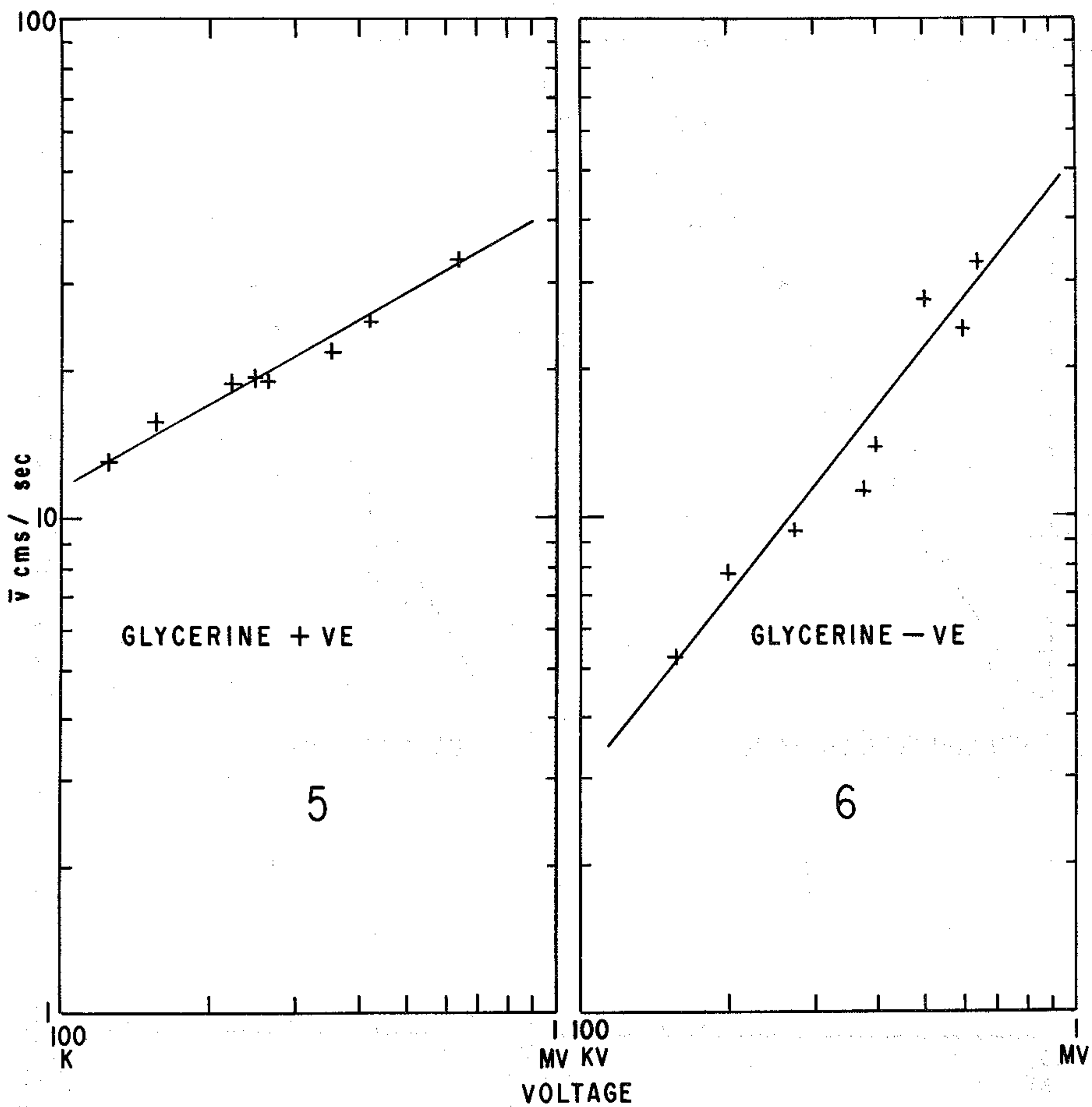
		r
Polythene, positive needle	$\bar{v} = (190 \pm 20)\, V^{1.00 \pm 0.08}$	0.97

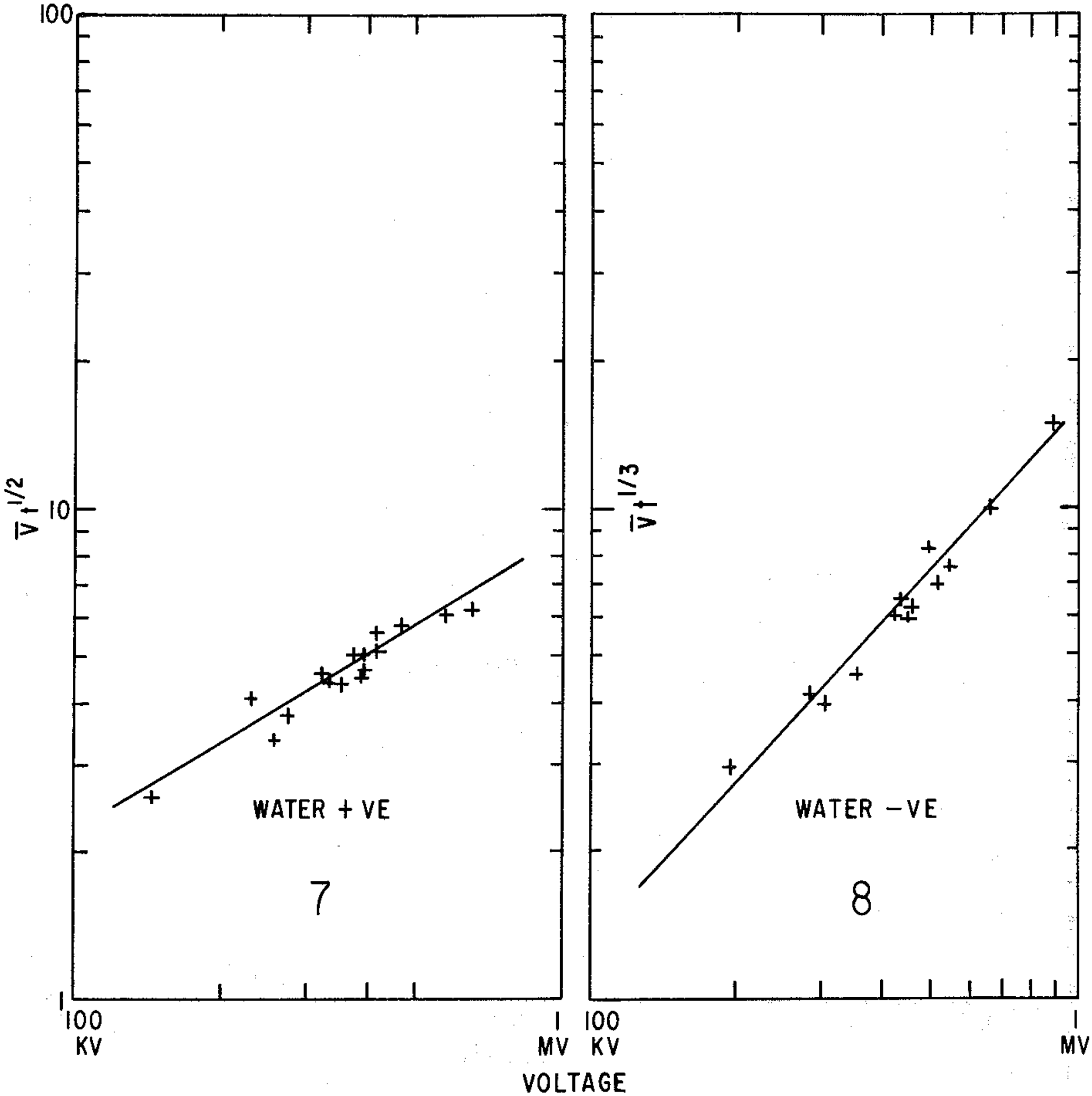
$\bar{v}$ in cms/μsec
V in Megavolts



100
10
1
$\bar{v}$ cms/μsec
OIL + VE
1
100 KV
1 MV
OIL - VE
2
100 K
1 MV
VOLTAGE


100
10
1
$\bar{v}$ cms/μsec
CARBON TETRACHLORIDE + VE
3
CARBON TETRACHLORIDE −VE
4
100 KV
1 MV
100 KV
1 MV
VOLTAGE


100
10
1
v̄ cms/ sec
GLYCERINE + VE
5
GLYCERINE — VE
6
100 K
1 MV
100 KV
1 MV
VOLTAGE



100
10
1
$\overline{V}_t^{1/2}$
WATER + VE
7
100
KV
1
MV
$\overline{V}_t^{1/3}$
WATER − VE
8
100
KV
1
MV
VOLTAGE

56 (8)