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STUDY OF TECHNOLOGY RELATING TO PLASMA CHROMATOGRAPHY SENSING TUBES

Period: AUGUST 6, 1978 to JANUARY 15, 1980

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SUMMARY

The construction of a Variable Parameter Plasma Chromatograph (VPPC) tube and another type of tube using standard parts from EV Inc. have been completed. Reassembling of the Mini tube has also been completed. A Nicolet Signal Averager (NSA 1170 Model) was acquired to read the signal out of the VPPC tube.

Several series of experiments with the various drift lengths of 2.54, 8.35, 11.67 and 16.67 cm have been conducted to find an optimum drift length for resolution and sensitivity. Results obtained so far indicate that the optimum tube length with the conditions employed in this work appears to be in the range of 15 to 17 cm, showing the peak II to peak III resolution of the positive reactant ion peaks to be between 1.70 and 2.00 at 140∼200°C. This resolution corresponds to 10∼40% improvement over the resolution achieved by PCP, Inc.

The signal current obtained from VPPC/NSA appears to be 4.0-8.0 x 10^{-10}A, which is more intense by two orders of magnitude than that obtained by the Beta VI/Boxcar integrator in the two gate mode. Signal to Noise ratio (S/N) improves directly as the square root of the number of scans and additional improvement can be made by 3 point curve smoothing (CS) operation i.e. $S/N = \sqrt{SCAN\ \#}\ (1 + CS\ effect)$. A typical S/N improvement obtained with signal scan number 4096 and CS 3 times appears to be 13.0.

A Corona Discharge Ionization Source (CDIS) was acquired from Sciex Ltd., for investigation as a more intense ion source. A testing procedure has been planned and the high voltage power supply needed to operate the discharge source is being acquired. The necessity for using higher voltages may require some alteration of the VPPC tube.

Although the construction of Mini tube and EV kit tube have been completed, shortage of time might not allow us to test them. Every effort will be made to cover the rest of the important experiments for variable parameters and CDIS application to VPPC as planned. (see Project Plan - Table I)

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STUDY OF TECHNOLOGY RELATING TO PLASMA CHROMATOGRAPHY SENSING TUBES

This report summarizes the work achieved during the 15 month period from August 16, 1978 to January 15, 1980

Five quarterly reports each covering the progress of a three months period have been submitted.

VPPC TUBE CONSTRUCTION: To conduct this study it was necessary to construct a special PC tube in which all the structural elements were easily replaceable. The details of the variable parameter plasma chromatography tube (VPPC) design have been previously reported (1). Since the tube components plug into a slotted base plate, individual drift and reaction region rings are easily replaceable to permit study of different configurations. The design concepts of a planar Bradbury-Neilson shutter which were formulated in work of the previous quarters were incorporated in the final design. The fabrication of grids with a mesh design was undertaken by ourselves due to the inability of the supplier to construct them with an etching technique within a reasonable time. These grids were unsuccessful. For the planar grids(2), a stainless steel wire with diameter 0.075mm from Hoskins Alloys Canada Ltd was used as the material for construction of the Bradbury Neilson shutter gates. Because of fragilness of the wire, and the thin ceramic plate used as insulation material on the stainless steel gating grid, a wire space of 1 mm and 0.5 mm was used as the minimum distance between wires. The effect of temperature on the gating grid was found to be negligible. Heating up to 260°C over a several days was performed and temperature gradients inside the oven of the tube were found to be small and negligible. The physical layout of the typical VPPC tube as shown in Figure 1 (top) is as follows: the total PC tube length, 14.21 cm, the length of reaction region, 5.87 cm with a ring ID of 1.91 cm, the length of drift tube 8.35 cm with an ID of 4.13 cm, the distance between the two gates of G_1 and G_2 is 5.81 cm, and the distance between G_2 and ion collector electrode is 2.54 cm. Figure 1 (bottom) shows the VPPC coupled with NSA 1170. The availability of Ni-63 foil for use (delivered July 2, 1979), finally enabled us to initiate the tests on VPPC tube.

Operation of NSA Model 1170: Prior to interfacing to the VPPC, the NSA 1170 was used on experiments using the positive reactant ion current from the PCP, Inc. Beta VI PC. In order to use the NSA with the Beta VI instrument, it was necessary to construct two special high speed low noise preamplifier heads, one using a Burr-Brown 3523-L amplifier as recommended by the Lawless report (3), and a second one using an LF 357 high speed bi-fet operational amplifier as shown in Figure 2. A $10^8 \Omega$ feedback resistor was used in the BB 3523L amplifier and LF 357 giving a bandwidth of 9 KH_z of 24 KH_z, respectively. Although there was more noise from the LF357, because of the greater bandwidth, it was discovered that the NSA 3 point smoothing reduced the noise to a level below that of the BB 3523L with 3-6 times of curve smoothing.

According to PCP Inc., it would be necessary to rebuild our Beta VI tube by moving the aperture grid from its position of 1 cm from the detector plate to about 0.010 inches (0.025 cm) from the detector before the NSA could be used. However, it has been found that by applying a higher voltage gradient to this grid, the performance is almost equal to that of a closer grid, and made rebuilding the tube unnecessary.

Data to determine the effect of field gradient and aperture grid voltage on resolution and sensitivity gave some interesting results. Shown in Figure 3 is the intensity of $(H_2O)_nH^+$ ion current detected with one gate mode (Gate 1 normal pulsed operation, 0.2 msec; Gate 2 opened). The current obtained by NSA appears to be 8.3×10^{-11} amp ($\sim 10^{-10}$A), which is 50 fold more intense than that obtained by the two gates mode operation and the box-car integrator. However the resolution observed was rather poor showing peak to peak resolution of a 1.0 to 1.3. In order to calculate the absolute ion current using the NSA 1170, the equation

$$i = \frac{(\text{normalized Cursor \#}) \times (\text{full scale volt range})}{\text{SCAN \#} \qquad \times \text{ ADC CHANNEL \#}} \times \frac{1}{R} \quad \text{--------} \quad (1)$$

was used, where R is input resistance value in ohms. In the two gate mode operation of the Beta VI PC, an Ohms Law equation was used to calculate the current i,

$$i = \frac{V}{R} \quad \text{--} \quad (2)$$

where V is voltage applied to the electrometer, "R" is input resistance in ohm (Ω). The maximum ion current appears to be obtainable when the aperture grid closure voltage corresponded to 7.5 ∿ 8.8% of the applied ion repelling voltage.

Based on the measured noise levels of the one grid and two grid modes the two grid mode might have some advantage for detection of signals showing much lower noise level than that observed by signal averager (one grid mode) for the spectra obtained with the same number of gatings for both cases. In the two grid mode, a much slower response time could reduce the noise contributed by the preamplifier itself. Therefore we may obtain lower levels of detectability when tuned only to specific ions. In the one grid mode however, when recording a total spectral scan the signal current obtained by the signal averager appears to be 50 folds more intense than the current obtained by two grid mode. S/N ratios observed for the one grid mode (by Beta VI/NSA) and two grid mode (Beta VI/Boxcar integrator) appears to be 15.2 and 10.0 respectively for the spectra scanned during 2 minutes (6000 scans) for both cases. This illustrates the superior effect of signal averaging in improving S/N.

Unlike boxcar integration which is a signal sampling technique employing integration for signal to noise enhancement, signal averaging is a real-time technique which stores a quantized representation of the sweep signal in digital memory and sums all subsequent sweeps as obtained. Noise on each sweep adds in quadrature or random, depending on the type of noise, while the coherent signal in each sweep adds algebraically. Thus there is a signal to noise improvement proportional to the square root of the number of signals summed. In addition to signal averaging ability by fast scanning, the NSA 1170 system includes three point smoothing capability. Three point smoothing is a numerical subroutine applied at the end of a series of scans which modifies each memory's contents by a weighted averaging with the two adjacent memory locations, according to the formula,

$$B = 0{\cdot}25A + 0{\cdot}50B + 0{\cdot}25C \quad \text{--------------------------------} \quad (3)$$

This tends to remove the randomness of incoherent signals and the higher harmonices of complex signals. The net result is a S/N improvement depending upon the sweep (Scan) number and the number of curve smoothing without a significant loss of intensity. Usually 3 to 6, up to maximum of 10 times, curve smoothing is required to smooth the noise level as reported previously (4).

Operation of VPPC/NSA 1170: After overcoming various minor troubles, the Ni-63 foil, delivered July 2, 1979 from New England, was installed at the second ring as planned. The first signal obtained from the VPPC tube was a single ion mobility peak with K_o=2.80 $cm^2/V.sec$ at 185°C. This K_o value appears to be 0.24 lower than that of $(H_2O)_nNH_4^+$ (3.04) observed previously with the Beta VI PC, and far higher than those of $(H_2O)_nNO^+$ and $(H_2O)_nH^+$ (5). After several confirmational runs with some compounds having different proton affinities, i.e. benzene, amines, and H_2O, it was concluded that this single ion must be $(H_2O)_nNH_4^+$ ion. The source of unusually high concentrations of NH_3 is not yet clarified. The NH_3 concentration has been observed to decrease steadily since the operation of VPPC was initiated. It has been found that changing the flow rates of carrier and drift gases will give the three distinctive reactant ionic peaks, depending on the measuring temperature. These facts suggest that the source of NH_3 might be the ceramic element containing the slots for replaceable elements. Thus, we have used the different flow rates to maintain the three well separated reactant ions. Under these instrumental situations, using other experimental conditions shown in Table II for the VPPC/NAS 1170 system, data have been obtained focussing on the following three aspects:(I) effect of signal averaging and curve smoothing on the S/N of ion mobility spectra, (II) measurement of peak width at half and full heights to evaluate drift tube length efficiency, $N=td/W_{\frac{1}{2}}$, (td=drift time in microsecond) and peak-to-peak resolution, $R=2(t_j-t_i/W_j-W_i)$ at various cell voltage with variable parameters of the tube. For these experiments, usually positive reactant ions and some product ions from typical samples are used, (III) Ion current intensity and results of other experiments performed for specific data. These results are summarized and discussed as follows.

Signal to Noise Ratio (S/N): All the undesirable signals which might be caused from periodic AC or DC current wave forms, electrostatic noise from the gate switching, corona discharge at sharp edge or corners, Townsend discharge (6), thermal effects from carrier and drift gas stream, induced current from the aperture grid, bias current from preamplifier, and other random noise sources have been studied. In an attempt to eliminate these noise sources, an electrostatic shield was placed approximately 1 mm in front of the collector. This did reduce the switching noise to a level in which it did not saturate the amplifier. Noise from the collector lead was minimized by constructing a rigid co-Axial cable from stainless steel tubing. For practical reasons, insulators were constructed initially from teflon, even though teflon is known to generate piezoelectric voltages within the amplifier. AC coupling was used because the DC component is not of great interest in the wideband amplifier. In this way input bias currents because less relevant, while input voltage and current became more important. Open loop gain, and gain bandwidth product were also of interest, so that an adequate bandwidth could be established. From output plots of the two grid mode, it was estimated that a half power bandwidth of 15 to 20 KH_z would be needed to obtain full information, while other systems had reportedly used 8 KH_z bandwidths (3).

Rounding and smoothing work on the edges and corners of the rings and grids also was done to reduce some of the noise sources. All semiconductors exhibit a phenomenon known as "1/F" noise, a noise spectral characteristic in which the noise power per unit bandwidth increases as the frequency of measurement decreases. The equivalent noise performance of the two-grid mode can not be improved by further averaging because of the 1/F spectral character of its noise.(3).

After baking the VPPC tube at 225°C over 48 hours, background noise current at various voltages was checked without the Ni-63 foil inserted. The noise current was found to be 4.7×10^{-9}A, 9.2×10^{-9}A and 1.7×10^{-8}A at applied voltages of 500, 1000, and 1500 volts respectively. By grounding the ion collector using a guard ring, the background noise current was significantly reduced to 10^{-12}A. Under these circumstances further investigations of S/N was performed. S/N values were calculated using the NH_4^+ peak.

In signal averaging, multiple repetitions of a signal are summed linearly and stored, while non-coherent signals such as noise added in the ratio of square root of the number of scan. A quantitative curve smoothing effect to S/N enhancement was investigated using the positive reactant ion spectra from the VPPC. Two sets of positive reactant ion spectra, one to check the effect of signal averaging and 3 point curve smoothing (top) and the other to check the effect of signal averaging (bottom) to S/N, are compared in Figure 4. These spectra were obtained under identical conditions (shown in Table) except that traces a-d are without curve smoothing, and traces a'-d' are with 3 times curve smoothing. This means that the difference of S/N value between these two set of spectra corresponds to the contribution to S/N enhancement from 3 times of 3 point curve smoothing. The measured S/N values vs scan number in both cases are plotted in Figure 5. One can notice that S/N is improved roughly in proportion to the square root of the number of scans and additional enhancement is made by 3 point curve smoothing operation i.e.

$$S/N = \sqrt{\text{SAN \#}}\ (1 + \text{CS EFFECT}) \text{ ------------------------- } (4)$$

The effect of curve smoothing is dependent on the signal averaging (SA) number and the number of CS. The effect of CS appears to be greater with a medium range number of scans (256 to 8192), while in the range of lower scan number or higher number of scans, the CS effect is neglegible,as shown in Figure 5. With 3 times curve smoothing operation, CS effect to S/N with scans of 64, 256, 1024, 4096, appear to be 0.33, 0.47, 0.59, and 0.64, respectively. The contribution to S/N is diminished with a larger number of scans, and CS operation contributes little, as shown in the extrapolated curve in Figure 5. With CS of 3 to 6 times, the loss of the intensity of ion peak height appear to be 3∿7% and no loss of resolution is observed. The S/N value obtained from trace d' in Figure 4(top) appears to be some what lower than the 15.2 obtained with the Beta VI/NSA 1170. Much efforts have been made to reduce the noise sources by rounding and smoothing edges and corners of elements inside the tubes to avoid arcing, Townsend discharge, and weak corona discharges. However, the main source of noise is not found yet. Fundamental investigation to find the source of noise is under investigation to improve base-line noise level. The noise effects are certainly specific to the way the VPPC tube is constructed, but these studies are expected to aid our design of the final tube for DREV.

RESOLUTION: In PC data, peak shapes are a function of gate width, which could be treated similarly to the calculation of number of plates, N, used in gas chromatography

$$N = 5.54 \left(\frac{td + t_g/2}{W_{\frac{1}{2}}}\right)^2 \quad \text{-----------------------} \quad (5)$$

where td is drift time, t_g is gate one pulse width, and $W_{\frac{1}{2}}$ is peak width at half height of peak respectively. Considering the drift length, ld, in PC corresponds to the column length in GC, height equivalent theoretical plates (HETP) is

$$\text{HETP} = \frac{ld}{N} \quad \text{-----------------------------------} \quad (6)$$

using Equation 12 and 18 of reference 7, Equation 6 becomes in the limit as t_g goes to zero or "ld" goes to infinity,

$$\text{limit HETP} = \frac{2\zeta kT}{eE} \quad \text{------------------------------} \quad (7)$$

ζ is the Townsend energy factor which equals the ratio of the mean kinetic energy of the ion to the mean thermal energy of the molecules in the drift region and also varies directly as E/P. Equation 7 is equivalent to twice the diffusion coefficient over the drift velocity.

In PC, the number of ions admitted by a gate is directly proportional to the gate width. The scan grid pulse width determines the range of ion velocities that will be allowed passage through the gate. Thus the gate width is expected to affect both resolution and sensitivity. However, both of these are competing parameters, i.e. resolution is increased at the expense of sensitivity and vice-versa. Although various definitions for resolution in PC may be possible, the following two definitions, one based on the definition of Equation 5 and the other, peak to peak resolution which is used in gas chromatography were used to evaluate resolution of ion mobility spectra:

$$N = td/W_{\frac{1}{2}} \quad \text{-----------------------------------} \quad (8)$$

where N is length efficiency and td is drift time of ion in msec, $W_{\frac{1}{2}}$ is peak width at half height in msec. Peak to peak resolution "R" is defined,

$$R = 2\ (\Delta td/W_{II} + W_{III}) \quad \text{-------------------------} \quad (9)$$

where "R" is peak to peak (two adjacent peaks), Δtd is drift time difference between peak II and peak III, and W_{II} and W_{III} are the respective widths of the peaks II and III at their base for which the resolution is being determined.

To determine the optimum high voltage range for the best resolution evaluated by the Equations 8 and 9, the voltage effect to the peak II and peak III resolution "R", length efficiency 'N', and intensity changes of $(H_2O)_nH^+$ (peak III) has been investigated with an injection gate width of 200 μsec. The vertical scales on the right side of the Fig. 6 show the length efficiency "N" and relative ion current intensity change of $(H_2O)_nH^+$ normalized by putting the intensity at 3100 volts as 100 units. Both efficiency "N" and resolution "R" increased as cell voltage increases showing a maximum region (N=40, R=1.60) in the applied voltage of 1700 to 2500 volts range. Considering the fact that if R=1.0, the resolution of two equal area peaks is approximately 98% complete, and if R=1.5 baseline separation (99.7% resolution) is achieved, the resolution obtained, which is 1.60, corresponds to ∿90% separation. The current intensity appears to be increased almost linearly as voltage increases. This causes both efficiency and resolution as well as ion intensity to increase upto an applied voltage 2300 volts. The conclusion made by French et al using equation 21 of reference (8) about the voltage effect on resolution of ion mobility spectra is applicable only in this region with the experimental conditions employed in this work. With voltage higher than 2300 (162V/cm) to 2500 volts (176 V/cm), both resolution and efficiency decrease sharply. Based on these results, the optimum voltage range to obtain well resolved ion mobility spectra from these data lies in the range of 2000-2800 volts or field gradient 141V/cm to 198 V/cm without severe loss of ion intensity. After these results were found, experimental measurements to evaluate resolution with various drift lengths have been performed in the range found above.

Variable Drift Length Effect to Resolution: After solving various experimental problems (9) encountered during length and voltage changes, we have been able to complete the tests with drift lengths 2.54, 8.35, 11.67, and 16.67 cm. Figure 7 shows a normalized positive reactant ion spectra obtained with drift tube lengths 2.54, 8.35, 11.67, and 16.67 cm (traces a-d). These spectra show how the drift length affects the peak shapes and peak to peak resolution. Figure 8 shows two plots of efficiency "N" and "R" vs drift tube length with a fixed field gradient (197-198 V/cm) which was found as an optimum field gradient from the results shown in Figure 6. It can be noticed that the drift length of 16-17 cm seem to be within the optimum range of drift length showing peak to peak resolution ∿1.70. Figure 9 shows a comparison of the two drift tube length efficiencies, one obtained by our work and the other by McDaniel et.al. (10), although the experimental conditions are different. The curve connected with closed squares shows the efficiency curve obtained with VPPC tube. A good comparison can be observed between the data obtained by our work (760 torr) and those (curve connected with open circles) of McDaniel et.al. (0.42 torr) (10). No great increase in the efficiency "N" is observed with a drift length change from 11.67 to 16.67 cm. The drift length of 16.67 cm seems to be just about a peak position of this curve, although it may be increased slightly at longer drift lengths. A demonstration of increased resolution with sample was previously reported (4). This result shows the resolution increase rate of reactant ions is applicable to the product ions also if the product ions do not undergo clustering reaction with reactant ions.

Experiment on Grid Wire Space and Its Effect Based on the results obtained from the study of correction of wave form distortion (9), it has been suggested that narrower wire spacing and optimization of gating voltage followed by narrowing the wire spacing could improve ion current intensity, resolution, and S/N. For comparison purpose, the wave form of the Beta VI PC and the VPPC were examined. The wave form of the Beta VI PC was found superior to that of VPPC. The details of VPPC wave form has previously reported (4). After this wave form was corrected, the half width ($W_{\frac{1}{2}}$) of VPPC were reduced to 260-320μsec from 320-360 μsec with a 11.67 cm drift length at 140°C, showing ∿20% improvement. Now our wave form is comparable to the wave form of Beta VI. After this wave form correction, the wire space on G_1 gate of VPPC was narrowed from 1.0 mm to 0.5 mm and the gate closing voltage was optimized, i.e. the voltage was reduced to ±13 volts from ±30 volts. To compare the $(H_2O)_nH^+$ ion intensities for the four different conditions (shown in Figure 10) relative intensities were normalized to plot in absolute current values by Equations 1 and 2. The ion current from the VPPC appears to be roughly greater by one order of magnitude than that observed from Beta VI. One good result obtained from the narrowed grid wire spacing is resolution improvement as shown in Table III,which contains the summary of the results obtained. By narrowing the wire spacing, the peak width at half height ($W_{\frac{1}{2}}$) was reduced to 440∿480 μsec from 520∿560 μsec giving a length efficiency "N" 46.8∿56 and peak II to peak III resolution "R" 1.70 to 1.80.

Application of CDIS to VPPC Tube: After receiving the CDIS from Sciex Ltd., February 7, 1979, a close look at the source was held to plan experimental procedure. A high voltage is needed for both the corona element and the VPPC tube. Limited capability of voltage supply with our Fluke Model 4088 HV supplier presently available will permit us to test a maximum voltage (V_n) 5000 volts. This gives a maximum electric field gradient 211 V/cm with a assumed drift length 8.35 cm. Figure 11 shows the physical schematic of the source (top) and the pin-point source (bottom) together with Sciex test system outline. From the principle of the source, a very high noise level is expected from the source. Also considering the close distance 0.35 cm from the source to the collector plate used by Sciex Ltd., considerable loss of ion current is predicted when the source is applied in PC. Figure 12 shows data ploted by us, using the raw data supplied by Sciex, showing maximum current production conditions.

Every effort will be made to expedite the rest of our project, including drift ring ID test and CDIS application to VPPC tube following the work schedule plan shown in Table I. Although the constructions of Mini tube and EV kit tube were completed, shortage of time forces us to shelve testing of these two tubes at the moment.

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TABLE I PC PROJECT WORK SCHEDULE FOR THE PERIOD OF FEB. - JULY 1980

FEB. 25, 1980

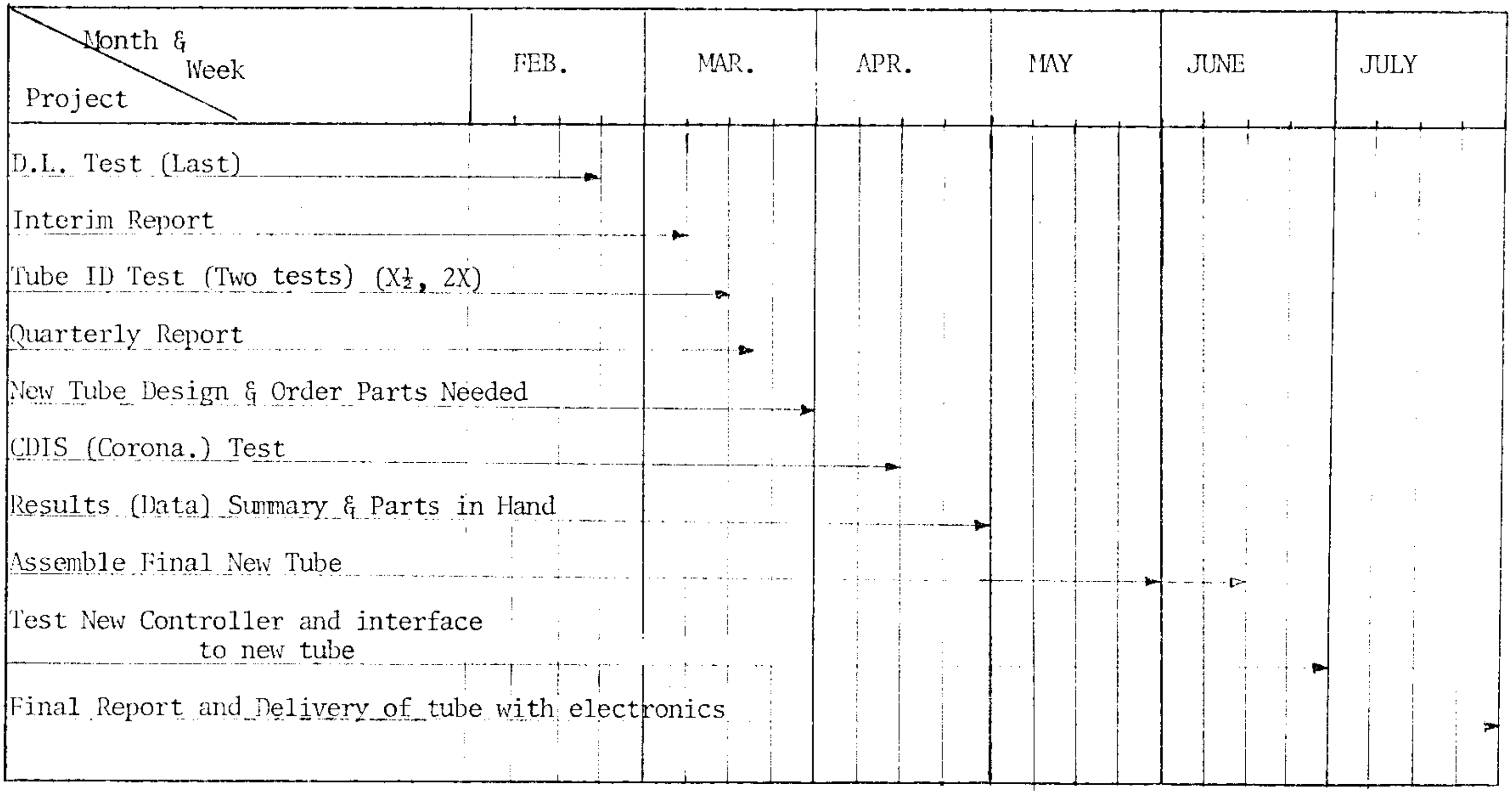


TABLE II

Experimental Conditions for VPPC/NSA 1170
VPPC:
TUBE Temperature: 136°-153°C, 200-215°C
Applied Voltage: +0-4300 volts
Pressure: 727.2-736 torr
Carrier Gas: 30-750 mls/min
Drift Gas: 400-750 mls/min
Gate width: 0.2 msec (G_1)
Time base: 20 msec
NSA 1170:
Sweep: 64-4096 (as shown in Figure)
Vertical Scale: 512-16K (as shown in Figure)
In-put filter: 10 KH_z
Full Scale: ±1/8 volts - 4 volts
ADC Res.: 6 bits - 9 bit

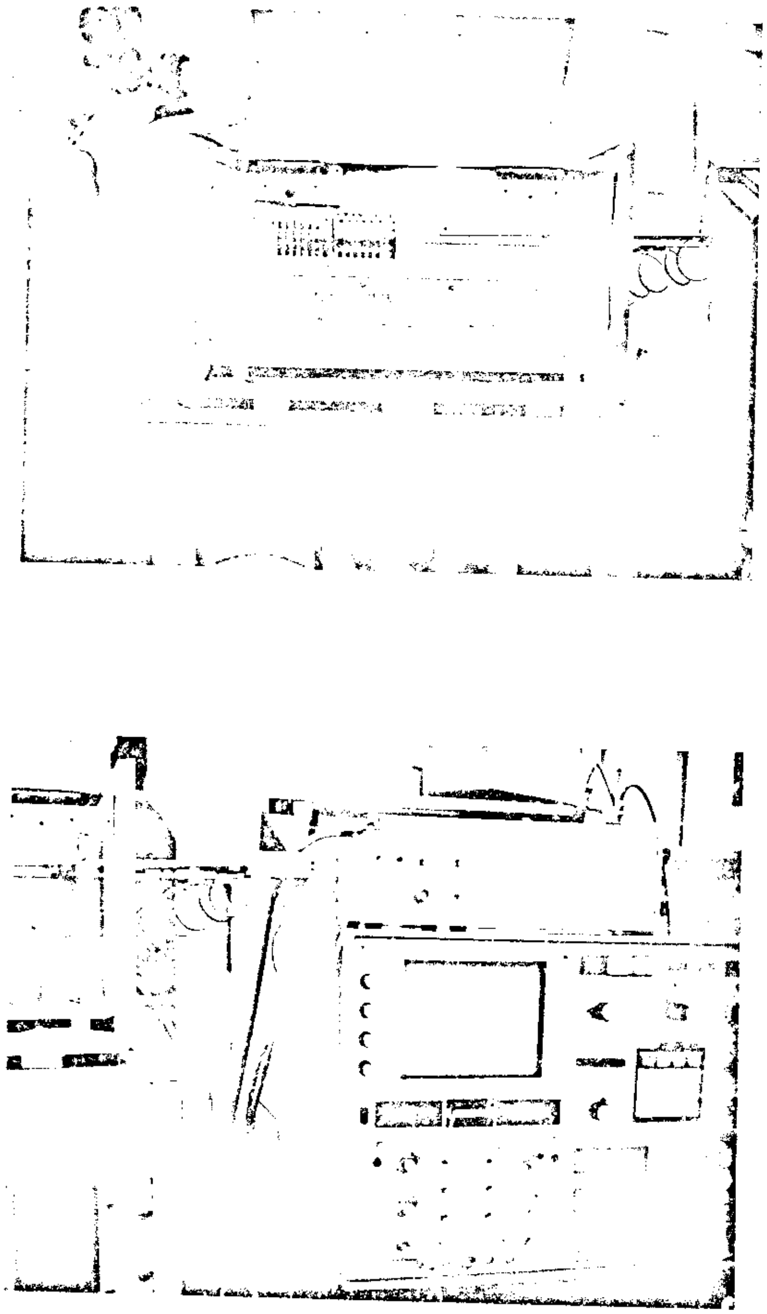
TABLE III

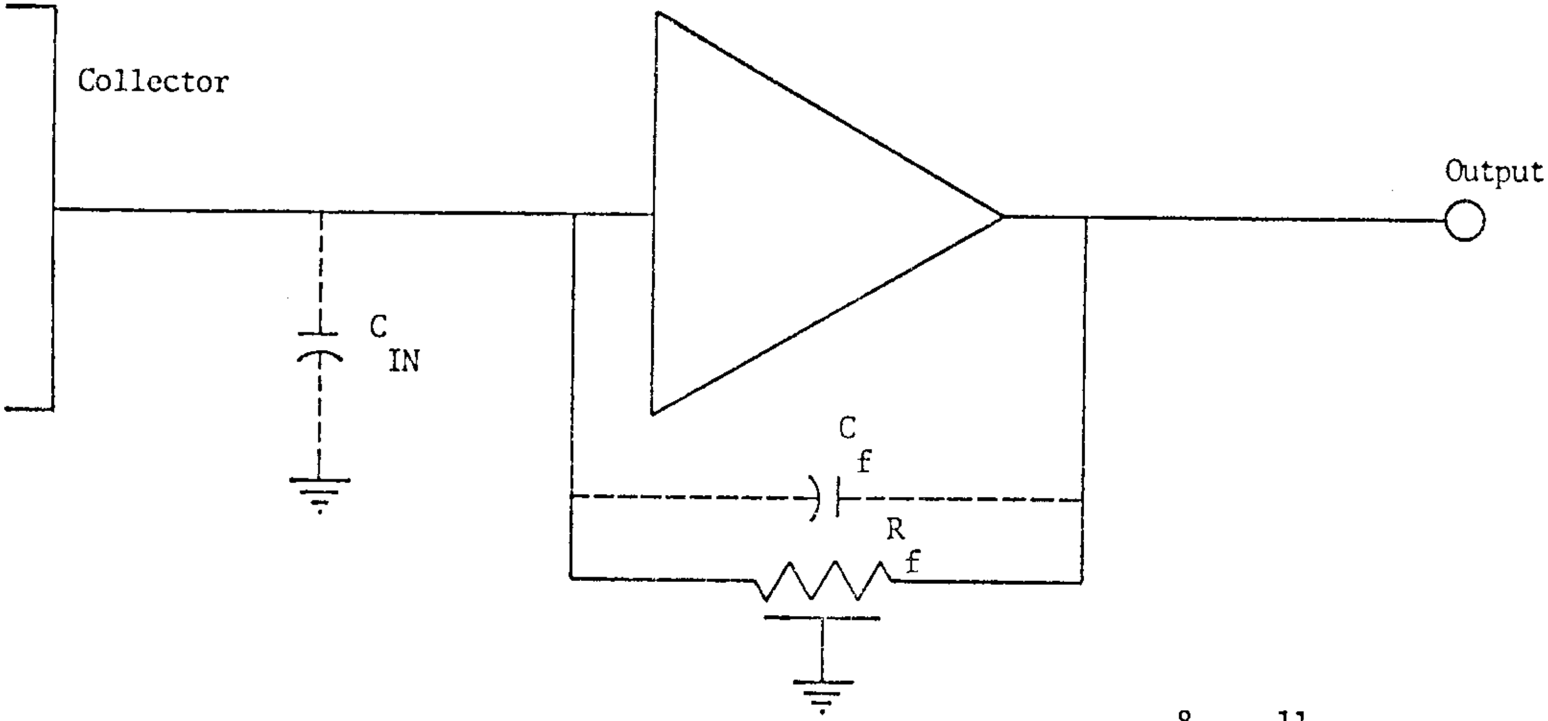
For Peak III = $(H_2O)_nH^+$
E = 197-8 V/cm,
0.2 msec/G_1 MODE

Drift Length	Peak III Width at ½ Height($W_{\frac{1}{2}}$)	Peak III Width at base line	Length Efficiency (N)	Resolution (R)	Remarks
2.54	250 µsec	500 µsec	10.9	0.78	N_2 Carrier & Drift gas 380, 350 ml/min Reaction Length: 11.67 cm + 2800 Volt, 145°C
8.35	340 µsec	900 µsec peak (II) = 1050	30.7 - earlier 34.8 - later	1.40	140°C Reaction Length: 5.86 cm Others: Same as above + 2800 V.
11.67	380∿460 µsec 320∿360 µsec at 215 °C	940 µsec peak (II) =960 µsec	41.1(at +3000 V) 37.5 (at +2800 V)	1.51 2.00 (at 215°C)	141°C, Carr, 350ml/min Drift, 750 ml/min Reaction L: 2.54 cm +2800 V
16.67	520 µsec	1200 µsec peak (II) =1120	43.0	1.69	147°C, Carr, 350 ml/min Drift, 750 ml/min +3800 Volts Reaction L: 2.54
16.67	440-480 µsec	1200 µsec	46.8-56	1.70-1.80	148°C, Carr, 30ml/min Drift, 475 ml/min Reaction L: 2.54 cm G_1 wire space 0.5 mm Gate voltage ±13 volts

Note: Error range ±10% for peak width.
Overal $(H_2O)_nH^+$ ion current observed, 4.0-8.0 x 10^{-10}A
Overal S/N observed, with 6000 scans (corresponds 2 minutes scan in two gate mode) 10 - 15 range
Unless otherwise shows G_1 wire space is 1.0 mm
Unless otherwise shows G_1 gate voltage ±30 volts.

Fig. 1

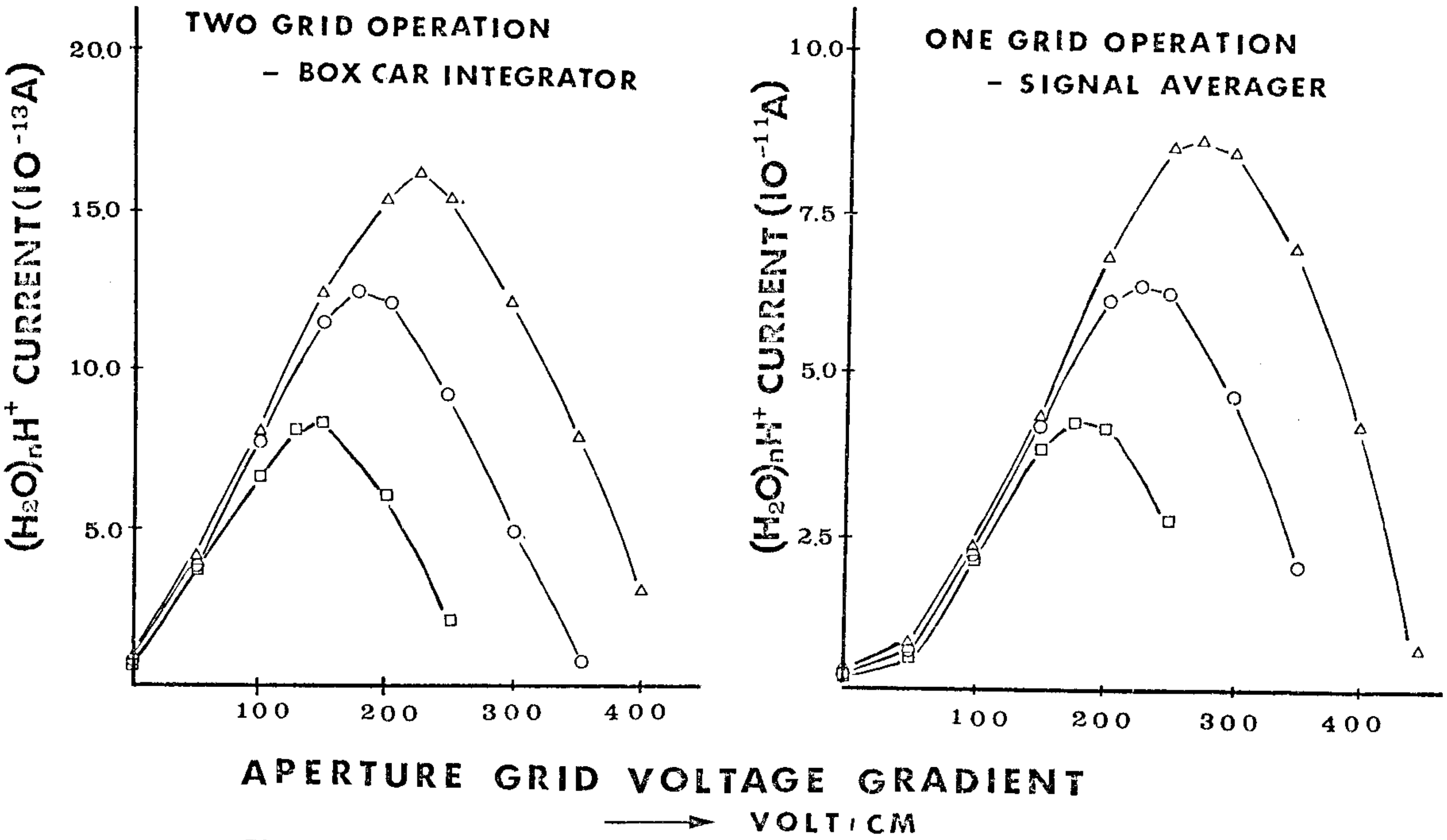




$R_f = 10^8$ to 10^{11} ohms

$C_{IN} = 60$ pf

Fig. 2

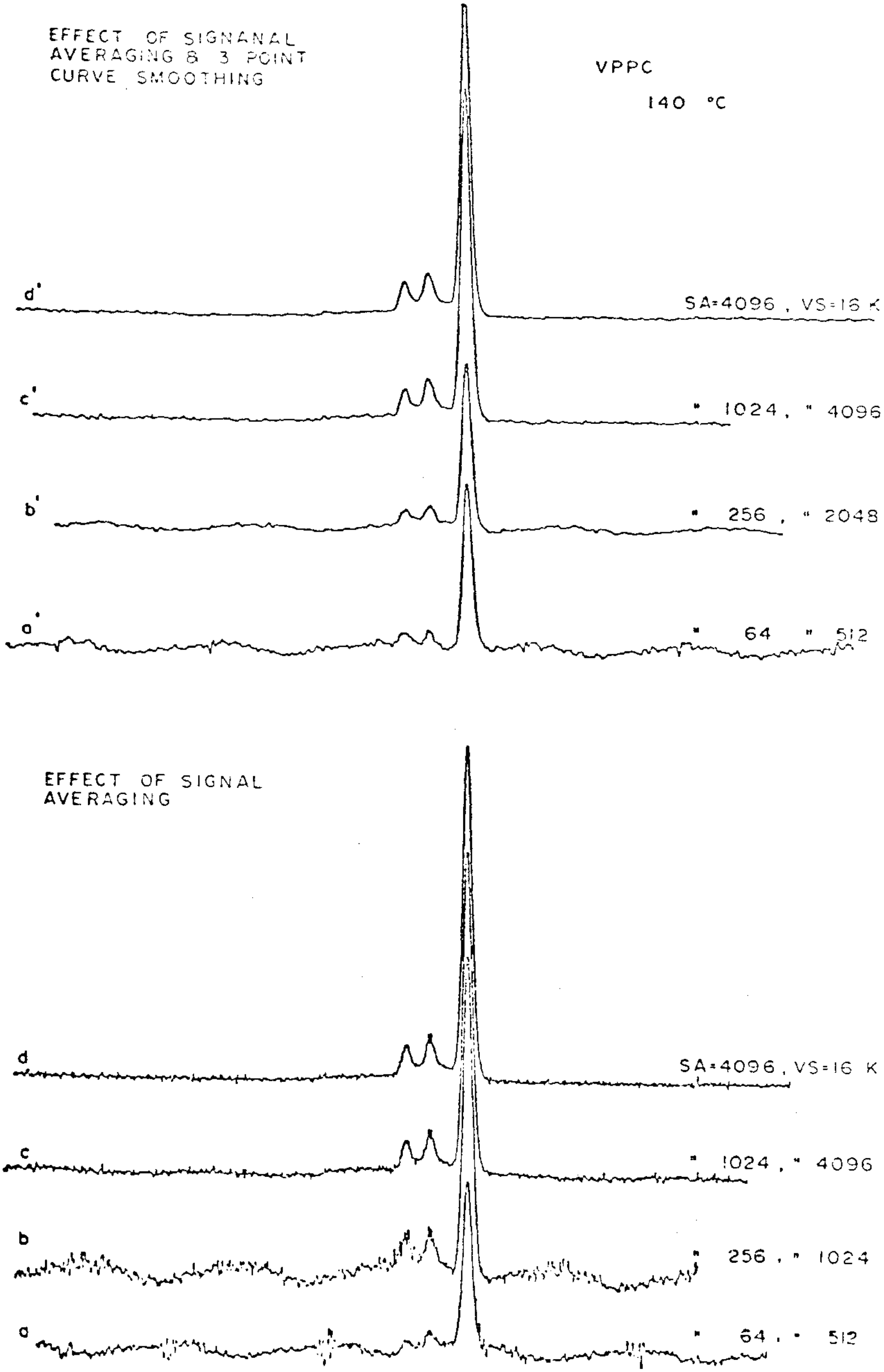


Tube Electric Field Gradient : □, 143 V/cm ○, 179 V/cm △, 214 V/cm

Injection Pulse : 0.2 msec

Fig. 3

Fig. 4


EFFECT OF SIGNANAL AVERAGING & 3 POINT CURVE SMOOTHING
VPPC
140 °C
d'
SA=4096 , VS=16 K
c'
" 1024 , " 4096
b'
" 256 , " 2048
a'
" 64 " 512
EFFECT OF SIGNAL AVERAGING
d
SA=4096 , VS=16 K
c
" 1024 , " 4096
b
" 256 , " 1024
a
" 64 , " 512

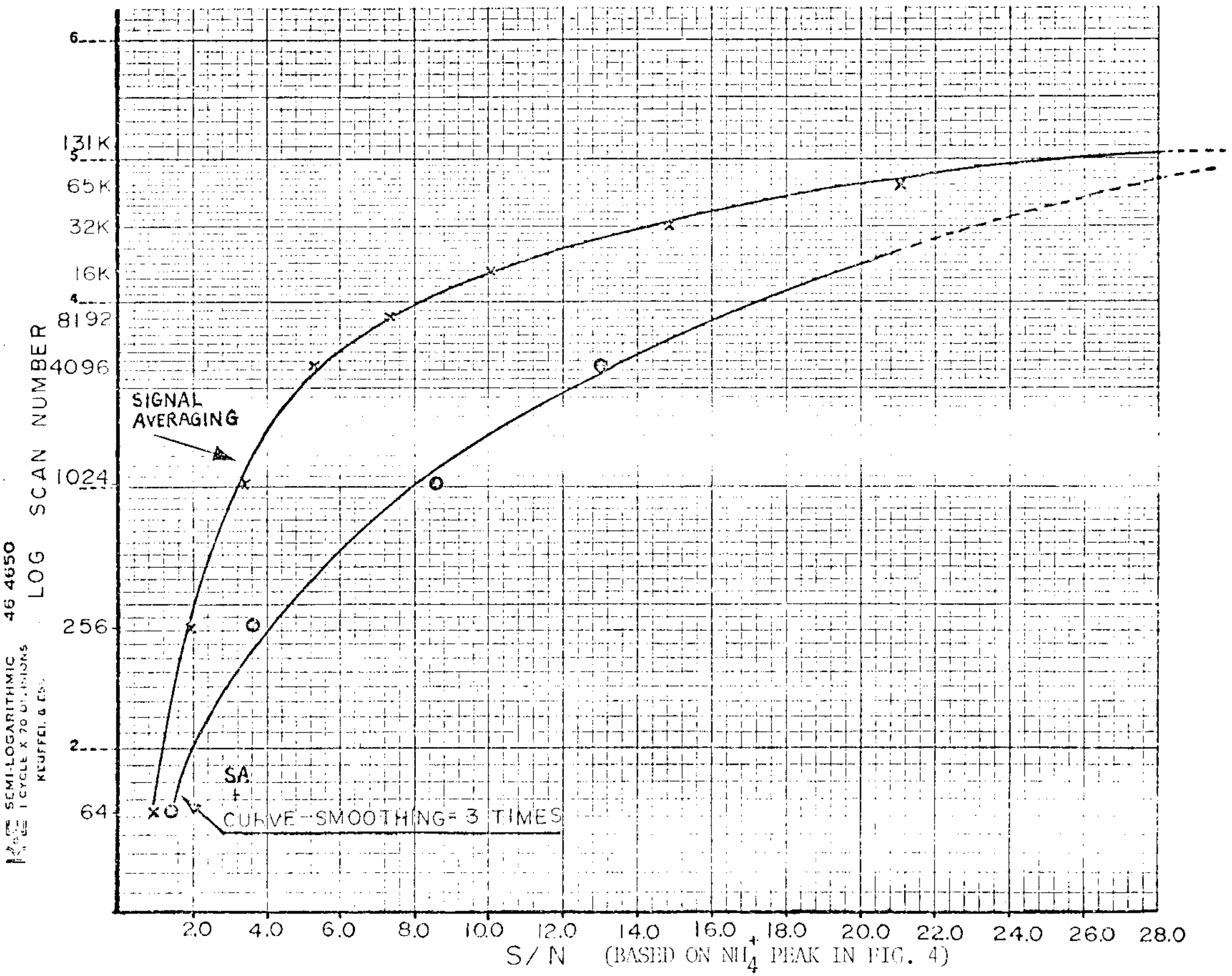
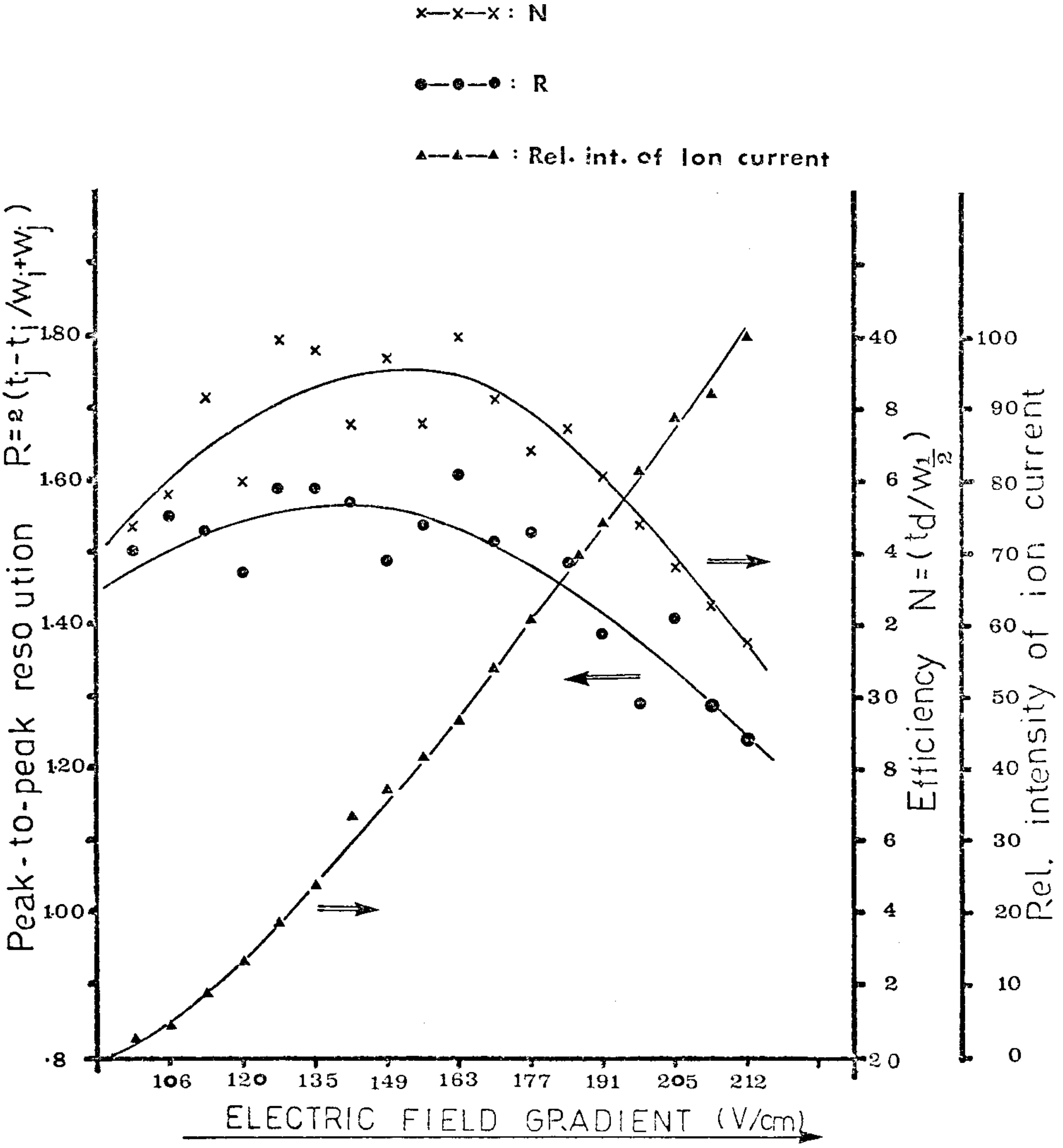

LOG SCAN NUMBER
131K
65K
32K
16K
8192
4096
1024
256
64
6
5
4
2
SIGNAL AVERAGING
SA
+
CURVE SMOOTHING = 3 TIMES
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
S/N (BASED ON NH$_4^+$ PEAK IN FIG. 4)
SEMI-LOGARITHMIC 46 4650
1 CYCLE X 70 DIVISIONS
KEUFFEL & ESSER CO.

Fig. 5

Fig. 6

VOLTAGE EFFECT TO PEAK-TO-PEAK RESOLUTION "R" AND LENGTH EFFICIENCY "N"



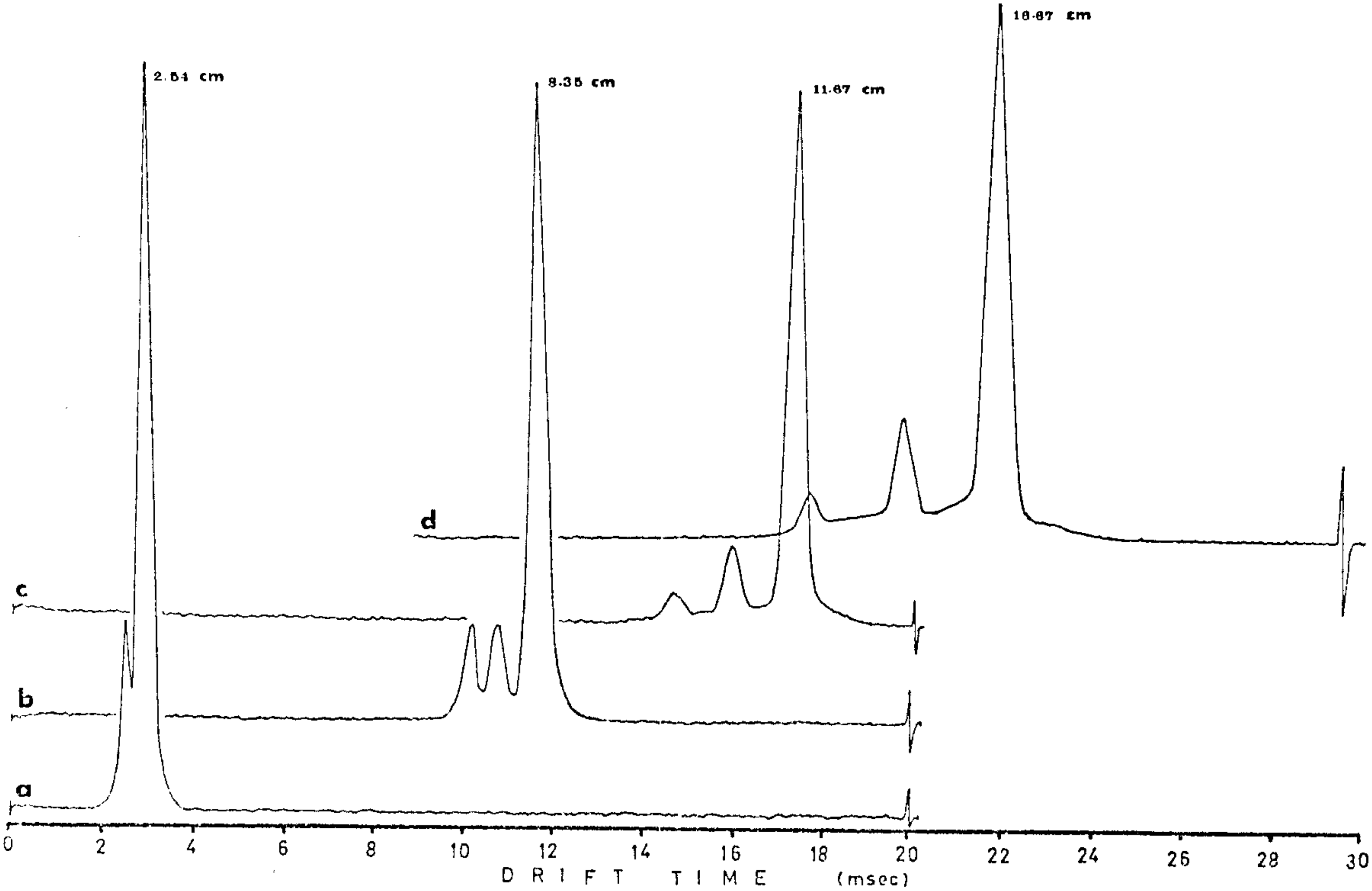

2.54 cm
8.35 cm
11.67 cm
16.67 cm
d
c
b
a
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
DRIFT TIME (msec)

Fig. 7

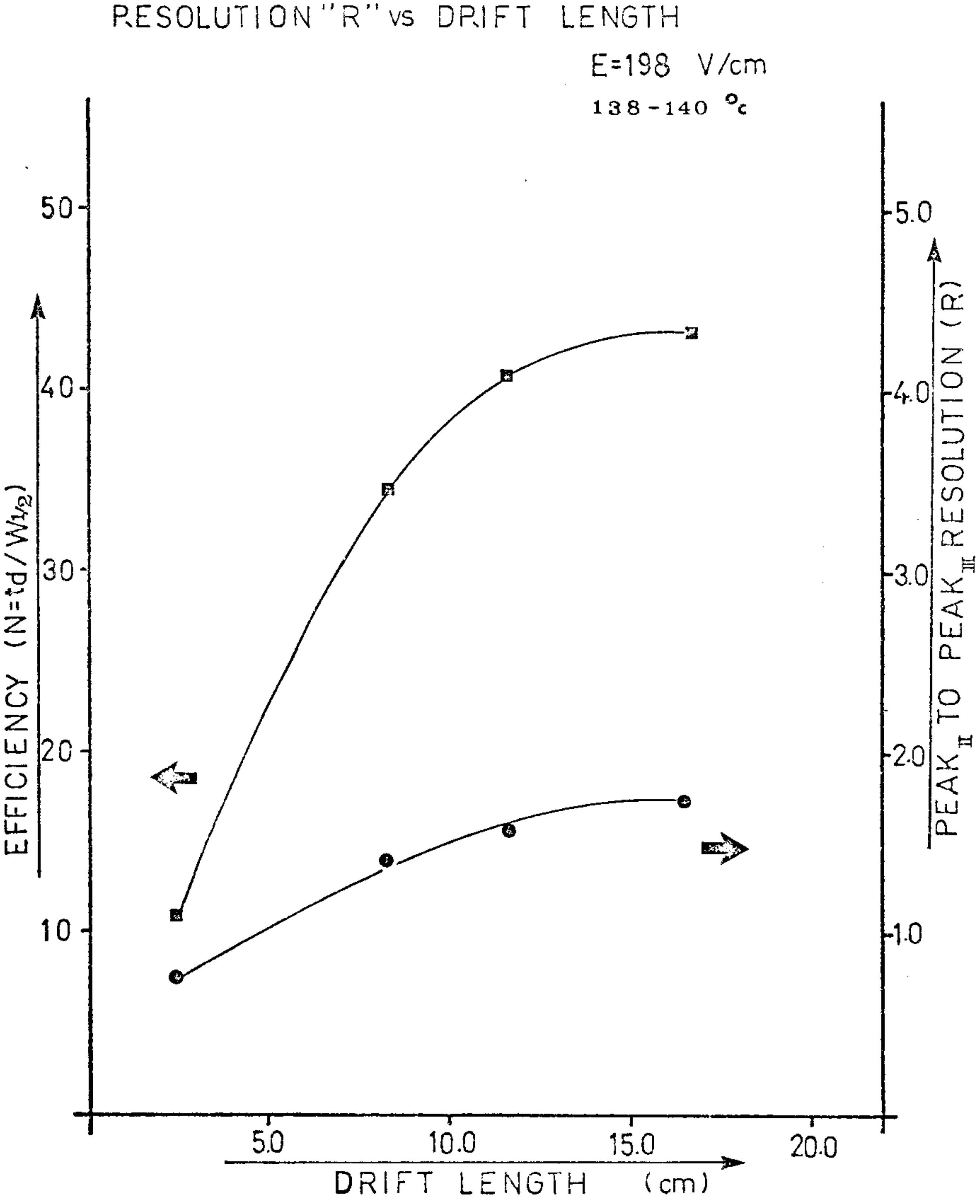

RESOLUTION "R" vs DRIFT LENGTH
E=198 V/cm
138-140 °c
50
40
30
20
10
EFFICIENCY (N=td/W1/2)
5.0
4.0
3.0
2.0
1.0
PEAK II TO PEAK III RESOLUTION (R)
5.0
10.0
15.0
20.0
DRIFT LENGTH (cm)

Fig. 9

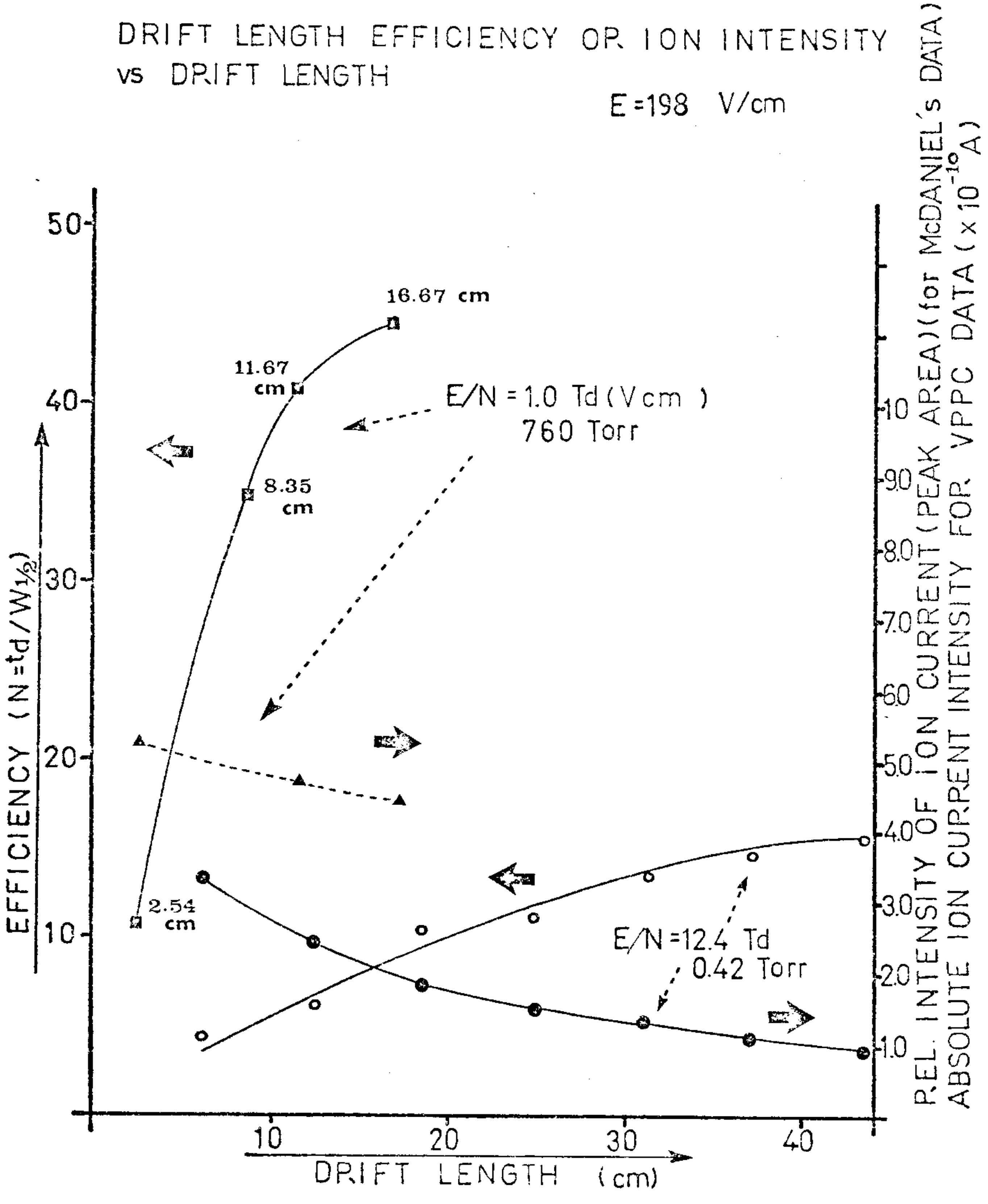

DRIFT LENGTH EFFICIENCY OR ION INTENSITY vs DRIFT LENGTH
E=198 V/cm
EFFICIENCY (N=td/W1/2)
10
20
30
40
50
16.67 cm
11.67 cm
8.35 cm
2.54 cm
E/N = 1.0 Td (V cm)
760 Torr
E/N =12.4 Td
0.42 Torr
REL. INTENSITY OF ION CURRENT (PEAK AREA) (for McDANIEL's DATA)
ABSOLUTE ION CURRENT INTENSITY FOR VPPC DATA (x 10^{-10} A)
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10
DRIFT LENGTH (cm)

Fig. 10

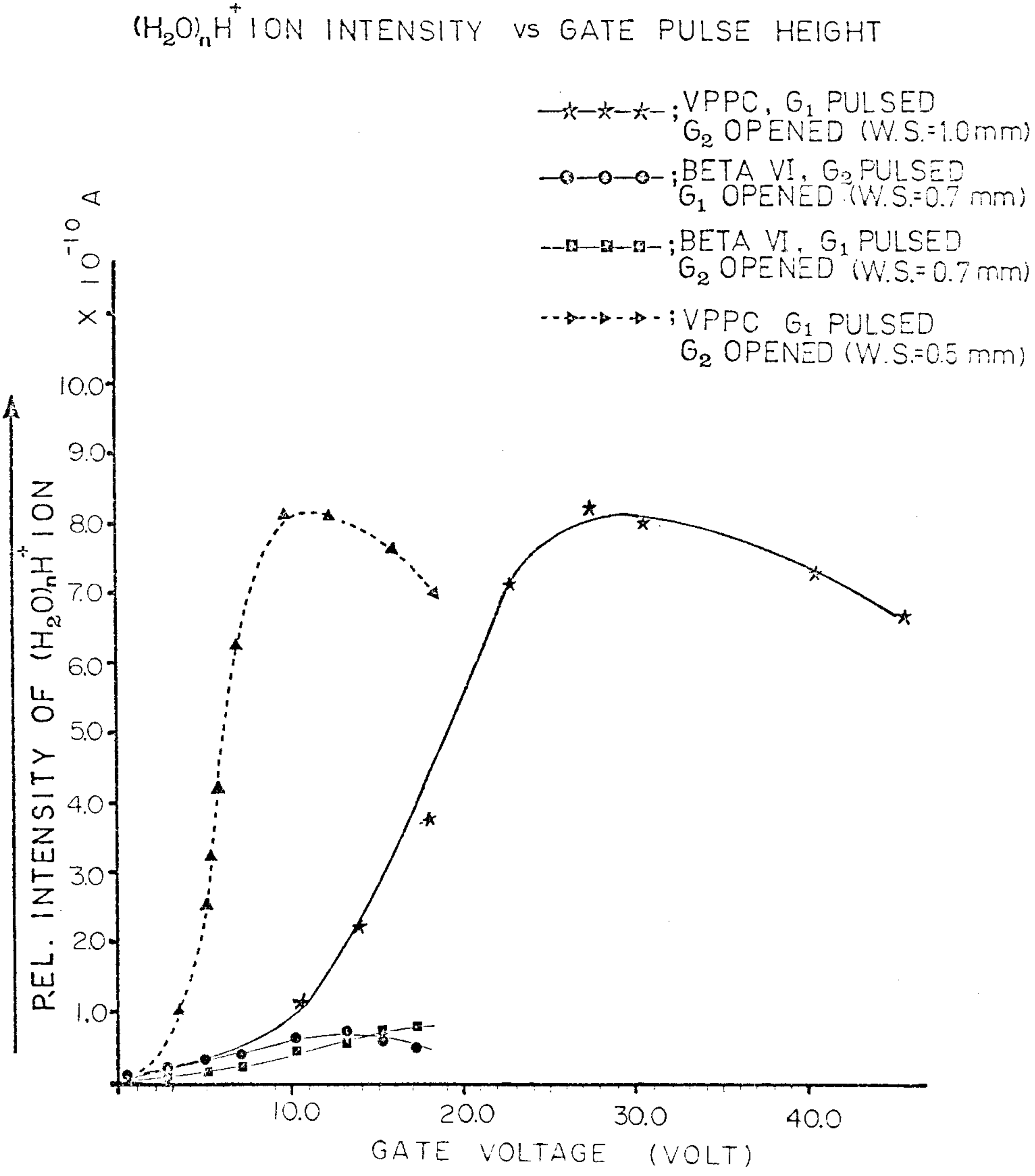
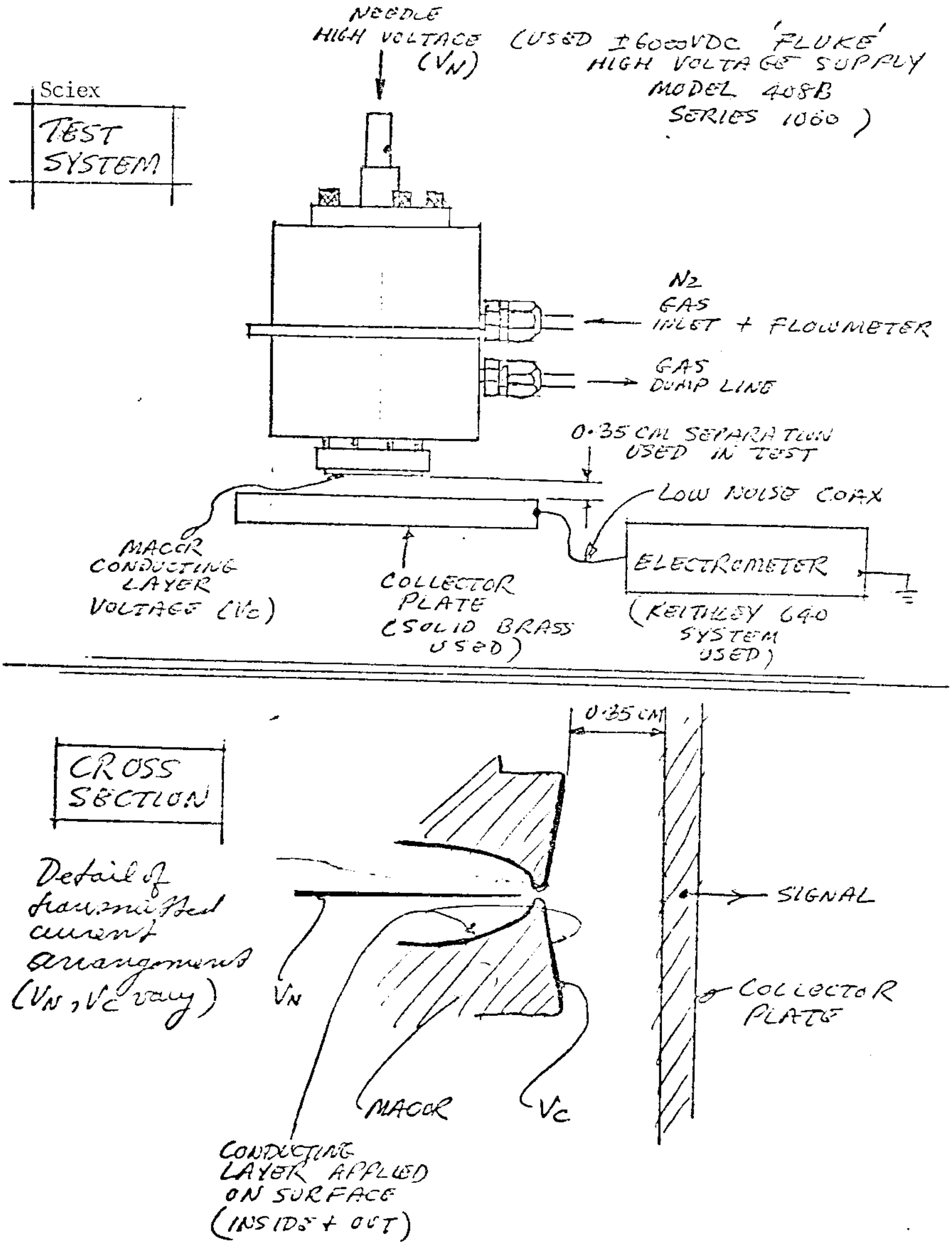

$(H_2O)_nH^+$ ION INTENSITY vs GATE PULSE HEIGHT
—☆—☆—☆— ; VPPC, G_1 PULSED G_2 OPENED (W.S.=1.0 mm)
—○—○—○— ; BETA VI, G_2 PULSED G_1 OPENED (W.S.=0.7 mm)
—□—□—□— ; BETA VI, G_1 PULSED G_2 OPENED (W.S.=0.7 mm)
- -▷- -▷- -▷- - ; VPPC G_1 PULSED G_2 OPENED (W.S.=0.5 mm)
REL. INTENSITY OF $(H_2O)_nH^+$ ION
× 10^{-10} A
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
10.0
20.0
30.0
40.0
GATE VOLTAGE (VOLT)

Fig. 11


Sciex
TEST SYSTEM
NEEDLE HIGH VOLTAGE (VN)
(USED ±6000VDC 'FLUKE' HIGH VOLTAGE SUPPLY MODEL 408B SERIES 1060)
N2 GAS INLET + FLOWMETER
GAS DUMP LINE
0·35 CM SEPARATION USED IN TEST
LOW NOISE COAX
ELECTROMETER
(KEITHLEY 640 SYSTEM USED)
MACOR CONDUCTING LAYER VOLTAGE (Vc)
COLLECTOR PLATE (SOLID BRASS USED)
CROSS SECTION
0·35 CM
SIGNAL
Detail of transmitted current arrangement (VN, VC vary)
VN
COLLECTOR PLATE
MACOR
VC
CONDUCTING LAYER APPLIED ON SURFACE (INSIDE + OUT)