INVESTIGATION OF THE FEASIBILITY OF SENSING TRANSIENT VELOCITY BY MEANS OF GASEOUS IONIZATION

by

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ACKNOWLEDGMENT

"In Jesus Christ we live and move and have our being." (Acts 17:28) The work for this thesis is no exception.

Twelve years ago at this time the author, a pagan, was in a completely unconscious and drowsy condition in the National Taiwan University Hospital, Taipei, Taiwan, Republic of China and was given up by doctors and loved ones except his wife. Now, twelve years later in April, 1968, he, a Christian, is doing his graduate study at an age of forty-four at the Virginia Polytechnic Institute, Blacksburg, Virginia, United States of America. The reader may imagine how deeply he is indebted to his Lord Jesus Christ for His grace. Before thanks are given to professors and people, a few words will be mentioned about how the Lord wonderfully guided the author's steps in doing this thesis. In September, 1966, in the third week of his first quarter in the Electrical Engineering Department, Iowa State University, Ames, Iowa, unexpectedly the author was suggested to drop one course and add another one about gaseous ionization offered by Dr. E. Nasser, his first major professor in his MS Program. After he was guided to Virginia Polytechnic Institute, Blacksburg, Virginia in March, 1967, he was further offered a research assistantship effective June, 1967 when he was first interviewed by Dr. W. W. Cannon, his third major professor for his Master's Program. But it was considered just as a job rather than a research for thesis then. When one day Dr. R.

H. Miller, his fourth major professor and also the present Chairman of his Committee, brought forward the idea of gaseous ionization approach to the research project and looked for an assistant with a background in the subject area, the author thanked the Lord in heart and understood why the drop and add of course occurred at Iowa State University. Due to the critical problems confronted academically the approach was considered pessimistic, although the professors agreed on that either a positive or a negative result would surely be worthy of being a Master's thesis. However, spiritually the author believed that for His name's sake, the Lord will do something to glorify Him through a useless utensil.

In carrying out the research, the author is also deeply indebted to many people for their contributions to this project. Suggestions and instructions given by Dr. W. W. Cannon and the interest and suggestions of Dr. R. H. Bond and Dr. E. M. Walsh proved invaluable. Special thanks go to Dr. R. H. Miller for his interest and instructions in deriving the basic formula such as the relation between the transient velocity and pressure change and the derivation of maximum sensitivity which lay the foundation for this thesis. His patient guidance and supervision throughout the program are appreciated. Thanks are also due all the professors in the Committee for their reviewing the thesis, and all the professors both in ISU and VPI, who taught and assisted the author. Particular thanks go to Dr. A. Robeson of the Department of Physics and Nuclear Science and Engineering, VPI for his providing the one-curie tritium source placed within

an area of one inch in diameter at the central portion of an electrode, a valuable idea and technique which made it possible to reach an optimistic result. Dr. Robeson also provided a room in the Reactor Laboratory for the experiment to be carried out. Close supervision in handling the radioactive source and kind assistance in answering and explaining whatever problems arose and furnishing equipment needed and heavier gas were given by Dr. Robeson, Dr. R. J. Onega, Dr. T. E. Leinhardt, Dr. R. F. Tipsword, Mr. S. L. Meyers, and other professors and friendly people in the Physics Department. His hat is off to all of them. Also many thanks are due Mr. F. Van Damme of the Chemistry Department, VPI, for his expert glass work, and Mr. Rudolph P. Hensley and Mr. Fred L. Bower of the EE Department, VPI, for their work in constructing the electrodes, washers, and other necessary equipment. Thanks are also due Dr. J. P. Wightman and Miss S. H. Wu of the Chemistry Department, VPI, for their kind assistance in setting up the vacuum system and Mr. T. Y. Tsai of the EE Department for his spending two days in helping the author run the experiment in the initial stage and all the friends in ISU and VPI and the VPI Chinese Bible Study Class and Sunday Schools of the Lutheran Churches both at Ames, Iowa, and Blacksburg, Virginia, and brothers and sisters in Christ both in Republic of China and the United States for their spiritual and academic assistance.

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Finally, hearty thanks are given his wife, Hui-lien Peng Huang, without her love and support in Christ it would be impossible for a retired air force major of an age over forty and a father of six children to leave his family in Taipei, Taiwan, Republic of China for the United States of America to continue his graduate study, not to mention a Master's thesis. Honor and glory be to the Lord Jesus Christ, Amen.

LIST OF FIGURES AND TABLES

I. INTRODUCTION

In the development of a transient velocity gauge to investigate the feasibility of using gaseous ionization current as an indication of the barometric pressure change resulting from acceleration of the container, the critical problems were:

1. What percent changes are achievable?
2. How can we achieve ionization level?
3. What is the time response?
4. How can a constant initial emission current be obtained from the source?

In April, 1946, Glenn L. Mellen[1] proposed the Radium-Type Vacuum Gauge, the Alphatron, which used radium as an ionizing source. The order of current realized from the gauge at 100 microns of air pressure was 10^{-11} ampere. J. R. O. Dowing, Glenn L. Mellen, and R. H. Vacca[2] did some research in improving the linearity over the entire range, a factor which will limit the sensitivity defined in Sec. 2.2 to unity. For constant initial emission current, tritium, the radioactive isotope of hydrogen, has been advantageously used in radiological vacuum gauges by J. R. Roehrig and G. F. Vanderschmidt[3]. With dry air in the chamber, such a source produces an ionization current less than 10^{-12} ampere[4] at a pressure of 10^{-3} mm Hg. The small current and the low sensitivity limit the use of existing ionization gauges for measuring transient velocity.

The purpose of this thesis is to investigate the following areas:

1. The behavior of tritium as an initial ionization current source.
2. Sensitivity of air and heavier gases at low and high voltages.
3. The behavior of the system at large and small electrode separation.
4. Time and frequency responses.
5. Methods of enhancing sensitivity.
6. Methods of increasing operating current to improve signal-to-noise ratio.

II. THEORY

2.1 Introduction

The gas of density ρ_o at pressure p_o in a closed chamber (Fig. 2.1) will take time to change its pressure from p_o to $(p_o + \Delta p)$ after being hit by a shock load of acceleration "a." It is shown in Appendix A that for time intervals much less than the system time constant, T,

$$\Delta p \propto \frac{\Delta \upsilon}{T} = a\frac{\Delta T}{T} \qquad (2.1)$$

where $\Delta\upsilon$ is the velocity change due to the acceleration.

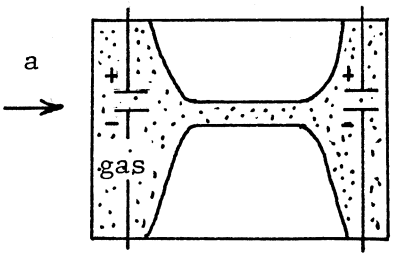


Fig. 2.1

Thus, $\Delta\upsilon$, the velocity change, can be measured in terms of Δp, the pressure variation.

In Appendix B it is shown that for a uniform cylinder of gas of length "L" subject to a longitudinal acceleration "a," the pressure differential over the length is:

$$\Delta p \propto a\rho_o L \qquad (2.2)$$

and

$$\Delta p/p_o \propto aL\rho_o/p_o \qquad (2.3)$$

Equation (2.3) indicates that, for a given acceleration and a given length of chamber, $\Delta p/p_o$ is directly proportional to the ratio of the initial gas density to the initial gas pressure, ρ_o/p_o. For a given volume of gas at a given temperature, the initial pressure is directly proportional to the initial density; therefore ρ_o/p_o is

independent of initial pressure for a given chamber at a constant temperature. In other words, $\Delta p/p_o$ will be independent of the initial pressure of the gas at the time the chamber is hit. However, the heavier the gas, the greater will be the value of $\Delta p/p_o$ for the same acceleration. Therefore, for a maximum $\Delta p/p_o$, it is better to use a heavier gas and a longer chamber regardless of the initial pressure.

For a given electric field and a given gas, the ionization current "i" varies with pressure p as follows[5]:

$$\ln (i/i_o) = \alpha d = A(pd)\exp[-B(pd)/V] \qquad (2.4a)$$

$$i/i_o = e^{\alpha d} = \exp[A(pd)\exp\{-B(pd)/V\}] \qquad (2.4b)$$

where i_o = current produced by irradiation of the cathode or the electron charge times the number of primary electrons per second liberated from the electron source which is also the cathode.

α = the number of electrons and positive ions (or ion-pairs) produced by a "Primary" electron at any point between the electrodes per cm of its path in field direction.

d = electrode separation

p = the pressure of the gas

V = voltage applied across two parallel electrodes

$A = 1/\lambda_1$, a dimensional constant for a given gas within a given E/p range

$B = V_i/\lambda_1$, a dimensional constant for a given gas within a given E/p range

E = V/d, electric field strength

$\lambda_1 = \lambda p$ at $p = 1$

λ = the mean free path (in cm per collision)

V_i = ionization potential of the gas

Therefore, theoretically the transient velocity of the gas chamber may be detected by means of the ionization current change.

From Eq. (2.11), Eq. (2.7) and Eq. (B.7) in Appendix B we have

$$\Delta p = p(\Delta i)/iS_p^i$$

$$= \Delta i/iAd[1-Bpd/V]\exp[-Bpd/V]$$

and

$$\Delta \upsilon = a\Delta t = 2T\Delta p/\rho_o L$$

$$= 2T\Delta i/\rho_o LiAd[1-Bpd/V]\exp[-Bpd/V] \qquad (2.5)$$

Therefore, for a certain initial operating pressure and current, the transient velocity is proportional to the current change.

2.2 Sensitivity

From Eqs. (2.1) and (2.3) we have

$$\Delta p/p_o \propto a[L\rho_o \Delta t/T]^{\frac{1}{2}}/p_o \qquad (2.6)$$

For a shock load Δt is very small compared with T, and the practical size of the chamber cannot be made too long; as a consequence, $\frac{\Delta p}{p_o}$ is not expected to be of considerable magnitude. If the ionization current is not very sensitive to the pressure variation, the idea of measuring transient velocity in terms of ionization-current change is impractical. Thus, we define sensitivity as

$$S_p^i = \frac{\Delta i/i}{\Delta p/p} = \frac{(\Delta i)p}{(\Delta p)i} \tag{2.7}$$

$$= \frac{d(\ln i)}{d(\ln p)} \tag{2.8}$$

We then proceed to investigate the maximum permissible value of S_p^i.

2.3 Measurement of Maximum Sensitivity

Let $pd = u$. Then Eq. (2.4) becomes

$$\ln(i/i_o) = Apd\exp[-Bpd/V]$$

$$= Au\exp[-Bu/V] \tag{2.9}$$

Differentiating Eq. (2.9) with respect to u, we have

$$\frac{d[\ln(i/i_o)]}{du} = A[1-Bu/V]\exp[-Bu/V] \tag{2.10}$$

By definition the sensitivity is

$$S_p^i = \frac{\dfrac{d(i/i_o)}{i/i_o}}{\dfrac{d(pd)}{pd}} = \frac{\dfrac{d(i/i_o)}{i/i_o}}{\dfrac{du}{u}}$$

$$= Au[1-Bu/V]\exp[-Bu/V] \tag{2.11}$$

To find the maximum value of S_p^i we proceed as follows:

$$\frac{dS_p^i}{du} = A[1-3(Bu/V) + (Bu/V)^2]\exp[-Bu/V]$$

$$= 0 \tag{2.12}$$

$$Bu/V = 2.62 \text{ or } 0.38 \tag{2.13}$$

$$\text{For } Bu/V = 2.62,\ S_p^i\Big|_{max} = -0.309VA/B \tag{2.14a}$$

$$\text{For } Bu/V = 0.38,\ S_p^i\Big|_{max} = +0.161VA/B \tag{2.14b}$$

For air[6], A = 8.6[1/cm (mm Hg)], B = 254[Volts/cm (mm Hg)] at E/p = 30 to 180 volts/cm (mm Hg). If V = 500 volts, d = 1 cm; then $S_p^i\Big|_{max} = -5.2$ at $(pd)_{max}$ of 5.16 cm (mm Hg). If E/p is within the range from 100 to 800 volts/cm (mm Hg), then A = 15[1/cm (mm Hg)] and B = 365[volts/cm (mm Hg)] for air, and $S_p^i\Big|_{max}$ is -6.35 at V = 500 volts. Equation (2.14) indicates that for constant A and B the maximum sensitivity $S_p^i\Big|_{max}$ is directly proportional to the voltage applied, V. However, for a given d, if V is increased to a certain value, breakdown[7] may occur before the value of pd can reach the value for maximum sensitivity (also see Sec. 4.5), since the gas breakdown voltage is a function of pressure. As the example indicates that the maximum sensitivity for air is only 5.2 at 500 volts and d = 1 cm, if at higher voltages S_p^i is not increased because breakdown occurs before pd can be adjusted to the value for $S_p^i\Big|_{max}$ to occur, then it will not be feasible to construct a transient velocity gauge based on the principle of gaseous ionization as far as air is concerned. Equation (2.14) also indicates for a given voltage, $S_p^i\Big|_{max}$ is greater for larger A/B which is inversely proportional to the ionization potential, V_i, of the gas atom.

Experimental results were obtained using air at low voltages, and the graphs of ion current versus the pressure-separation product (i Vs. pd) are shown in Fig. 2.2. By differentiating Eq. (2.4) with respect to (pd), the maximum of i/i_o is found to occur at pd = V/B, which is approximately 1 cm (mm Hg) for air at 350 volts. The observed value agrees with this calculated value. However, by

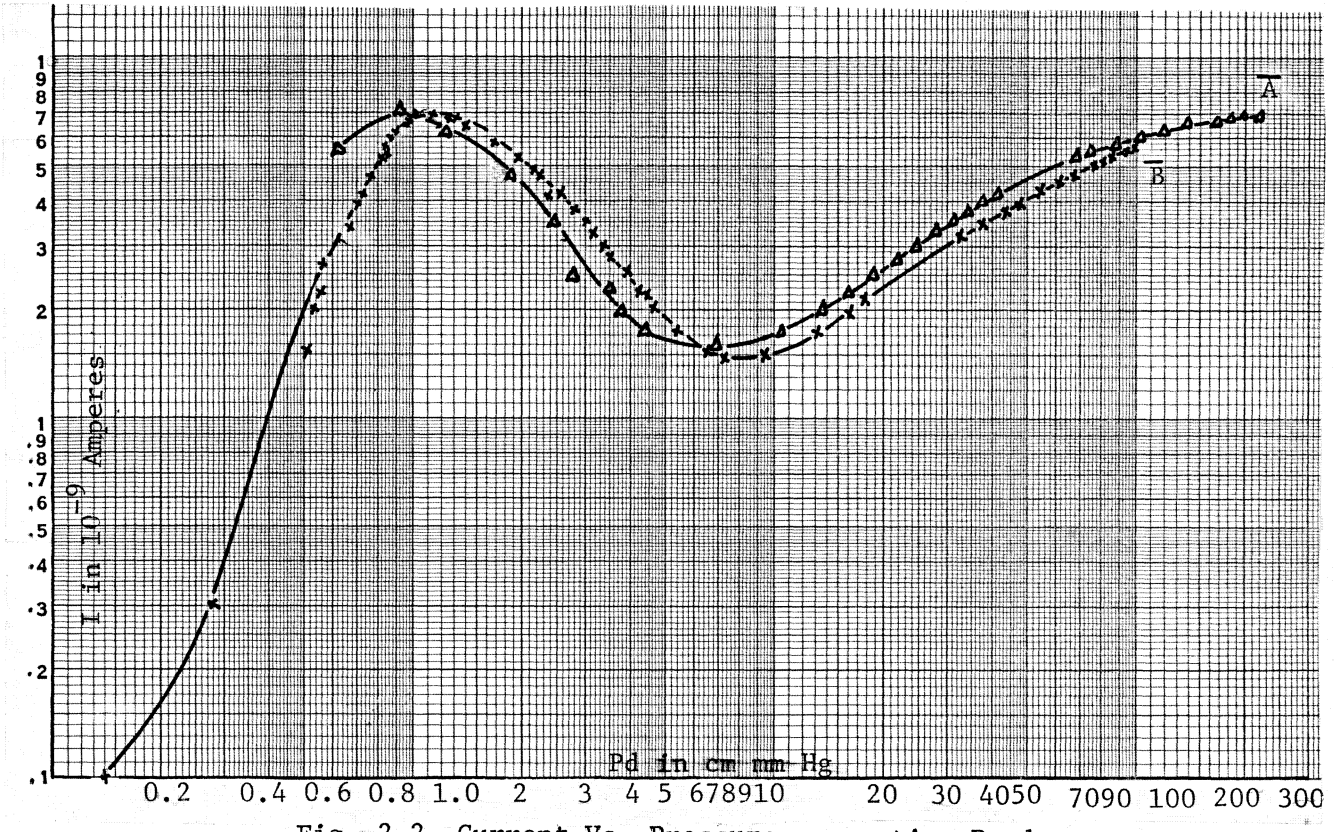


Fig. 2.2 Current Vs. Pressure-separation Product (i-pd curves) for (A), V = 366V. d = 0.31 cm (B), V = 357V. d = 0.14 cm with radioactive source #3 in air.

inspection of Eq. (2.4), it is seen that for both large and small values of p (or pd), i approaches i_o; but by inspection of Fig. 2.2 it is seen that i increases again after pd is increased to a certain value. Therefore, only one portion of the i vs. pd curve can fit the bell shape described by Eq. (2.4), even under low potential condition. The maximum sensitivity determined from the data in Fig. 2.2 is 1.91 for Curve $\overline{A}$ and 1.67 for Curve $\overline{B}$ as found in Sec. 4.1. These experimentally determined values are much lower than the calculated values. Therefore, to obtain the highest sensitivity, experiments must be performed at the highest possible potential without breakdown. Observed values shown in Sec. 4.4 are optimistic. A comparison of the calculated values of sensitivity with those determined experimentally and a discussion of the deviations are given in Sec. 4.5.

2.3.1 Maximum Sensitivity without Breakdown

It can be shown[8] that the breakdown potential, V_s, of a gas is

$$V_s = B(pd)/\{\ln(pd) + \ln[A/\ln(1 + 1/\gamma)]\} \qquad (2.15)$$

where γ is the total secondary emission coefficient.

Equation (2.13) indicates that $S_p^i\Big]_{max}$ occurs at

$$u = (pd) = 2.62\ V/B \qquad (2.16)$$

For operation below breakdown, the applied voltage across the electrodes should be kept less than V_s. Thus, we have

$$(pd) < \frac{e^{2.62}}{A} \ln\left(1 + \frac{1}{\gamma}\right) \qquad (2.17)$$

By differentiating V_s with respect to (pd), it is found that the minimum V_s occurs at

$$(pd)\,|\text{for } (V_s)_{min.} = \frac{2.72}{A} \ln\left(1 + \frac{1}{\gamma}\right) \tag{2.18}$$

and

$$(V_s)_{min.} = B(pd)_{min.} \tag{2.19}$$

Therefore, the (pd) chosen for maximum S_p^i and larger V_s will be either

$$\frac{2.72}{A} \ln\left(1 + \frac{1}{\gamma}\right) \leq (pd) < \frac{13.735}{A} \ln\left(1 + \frac{1}{\gamma}\right) \tag{2.20}$$

where the inequality is to avoid breakdown voltage and (pd) is in the same unit as $\frac{1}{A}$.

For air with $\gamma = 10^{-2}$ [8], A = 15, B = 365, the proper value for pd is $0.83 < (pd) < 4.2$ cm(mm Hg) or $(pd) < 0.83$ cm(mm Hg). In Sec. 4.5 comments are made about some of the observed results with regard to this point. Equation (2.20) is derived under the assumption that the voltage is low enough that the i vs. (pd) characteristic may be described by Eq. (2.5) and that the maximum sensitivity occurs at a value of (pd) equal to 2.62 V/B. It provides the range of pd for low potential condition. The parameters A and B are constant for a given value of $\frac{E}{p}$, and, thus, for a given separation they are constant for a given value of $\frac{V}{p}$. Equation (2.14) indicates that $S_p^i\Big|_{max}$ is directly proportional to V if A and B are kept constant. Experimental results in Sec. 4.4 agree with this point.

2.3.2 Ionization and Mean Free Path of Electrons in a Gas

An electron with a small energy is assumed to begin a mean free path λ. The least distance L_i the electron has to move in field

direction in order to be capable of ionizing at the next collision is

$$L_i = V_i/E \tag{2.21}$$

where V_i is the ionization potential of the gas atom in volts.

The mean free path of an electron in a gas is [9]

$$\lambda = 1/(\pi r^2 N_v) = kT/(\pi r^2 p) \tag{2.22}$$

where r is the radius of the gas molecular in meters, p, the gas pressure in Newtons/m^2, k the Boltzmann constant 1.38×10^{-23} joule/^oK, T in ^oK, and λ in meters.

For ionization to occur, λ must be greater than L_i. Thus,

$$kT/\pi pr^2 > V_i/E$$

and

$$E/p > \pi r^2 V_i/(kT) \tag{2.23}$$

If p is in (mm Hg), E, in volts per cm, then

$$\frac{E}{p}\left(\frac{V}{cm\ mm\ Hg}\right) > \frac{4}{3}\frac{\pi r^2 V_i}{kT} \tag{2.24}$$

Equation (2.23) will give the value of E/p for determining the secondary emission coefficient γ required in Eq. (2.20) for low potentials.

2.4 Factors Effecting Sensitivity

Equation (2.11) and (2.14) indicate that for given values A, B, and pd, the sensitivity, S_p^i, is directly proportional to V. The experimentally determined value in Sec. 4 is in close agreement with this point.

Equation (2.7) indicates that S_p^i will increase with p provided that the value of $(\frac{\Delta i}{i \Delta p})$ decreases at a less rate than p is increasing. The observed results in Sec. 4 are also in agreement with this.

Equation (2.3) indicates that $\frac{\Delta p}{p_o}$ is greater for heavier gases. If the sensitivity of heavier gases, S_p^i, is of the same order of magnitude as that for air, then $\frac{\Delta i}{i}$ will be greater than that for air. The observed results in Sec.4indicate that krypton behaves almost the same as air while it is 2.9 times as heavy as air.

The stronger the radiation source, the larger the order of magnitude of the current. If sensitivity is the same for the system with a stronger source as that with a weaker source, then $\frac{\Delta i}{i}$ will maintain the same for the same fractional change of pressure while the magnitude of the current and current changes will be magnified so that it will be easier to detect with less noise problem. The observed results in Sec. 4 indicate that with a source of one curie of tritium, the current level may be managed as high as 10^{-5} ampere, while the order of magnitude of sensitivity is still the same as for a system with a weaker radiation source.

For a constant $\frac{E}{p}$, increasing the separation d, permits a higher voltage to be applied without breakdown, and increases the sensitivity. However, if the source is placed in the central portion of the surface of one of the electrodes, then the larger the separation, the fewer the β - particles which will hit the oppositive electrode and fewer ionization collisions will occur. The observed result with a voltage of 11.5 KV at d = 0.80 cm indicates that such a

location of the radiation source does not increase the current level while it does decrease the sensitivity when separation is increased too much.

Since $S_p^i\Big]_{max}$ is proportional to A/B which, in turn, is inversely proportional to the ionization potential of the gas atom, V_i is a factor which must be considered in selection of a gas for greatest sensitivity.

2.5 Time Response

Let the electric field be E and the mean time between collisions, τ seconds. The force on an electron due to the field is -eE and its acceleration in the direction of the field is -eE/m, where m is the mass of an electron. The increase in velocity in a time, τ in a uniform field between collisions is $-Ee\tau/m$. Assume that in a collision the electron loses the directed velocity $-eE\tau/m$. Between collisions the directed component of velocity increases uniformly from zero to $-eE\tau/m$. Thus, the average directed drift velocity V_D is given by

$$V_D = -eE\tau/2m \tag{2.25}$$

and the mean free path of the electron in the gas, λ, is given by

$$\lambda = \tau|V_D| = -eE\tau^2/2m = eE\tau^2/(2m) \tag{2.26}$$

Thus, the mean free time between collisions for a single electron, is,

$$\tau = \sqrt{\frac{2m\lambda}{eE}} \tag{2.27}$$

and

$$V_D = \frac{eE\tau}{2m} = \sqrt{\frac{eE\lambda}{2m}} \tag{2.28}$$

The total time required for an electron, subject to collisions, to go from the cathode to the anode is

$$t = \frac{d}{V_D} = \sqrt{\frac{2m}{eE\lambda}\, d^2} \tag{2.29}$$

Since the mean free path of an electron in a gas of molecular density N_V is

$$\lambda = 1/(\pi r^2 N_V) \tag{2.30}$$

where $N_V = \frac{p}{kT}$ and r = the radius of the gas molecule, we have

$$\lambda = kT/(\pi r^2 p) \tag{2.31}$$

and $$t = [2m\pi r^2 p/(eEkT)]^{\frac{1}{2}} d = [2m\pi r^2/(ekTE/p)]^{\frac{1}{2}} d \tag{2.32}$$

If E, d, r, and T are kept constant while p is varying, then

$$t = K\sqrt{p}, \text{ where } K = \sqrt{\frac{2m\pi r^2}{eEkT}}\, d = [2m\pi r^2/(eEkT)]^{\frac{1}{2}} d$$

$$\frac{dt}{dp} = \frac{1}{2} K p^{-\frac{1}{2}},$$

$$dt = \frac{1}{2} K p^{-\frac{1}{2}}\, dp, \tag{2.33}$$

and

$$\frac{dt}{t} = \frac{1}{2}\frac{dp}{p} \tag{2.34}$$

Equation (2.4) reads

$$\frac{i}{i_o} = e^{\alpha d} \tag{2.5}$$

By the time the primary electron starting at x = 0 (cathode) arrives at x = d (anode), the current increases from i_o to i due to the collision of electrons with gas molecules on the way to the anode. We may say that the time required for the current to build up from i_o to i is

$$t = \sqrt{\frac{2m\pi r^2}{e\frac{E}{p}kT}}\,d = [2m\pi r^2/(ekTE/p)]^{\frac{1}{2}}d \qquad (2.32)$$

for constant p, temperature and E field.

For a step change of pressure, dp, from the operating pressure p, the time required for the current to build up is, by Eq. (2.32),

$$dt = t(dp)/2p \qquad (2.35)$$

Furthermore, for a certain value of E/p, the drift velocity of ions is definite[10], the time required for the ion to move across the gap of separation d is

$$t = \frac{d}{(V_D) \text{ at certain } E/p} \qquad (2.36)$$

Example 1: For Hg vapour at E/p = 142 volts/cm (mm Hg) and T = 600°K, and d = 0.1 cm, t = 35.8 r_{Hg}. Where r_{Hg} is the radius of Hg molecule in meters. (1.25×10^{-10} m.)

t = 4500 μμsec.

For a change of pressure of $\frac{dp}{p} = 0.5$, the change of time is

$$dt = \frac{1}{2} \times 4500 \times 0.5 = 1125 \text{ μμsec.}$$

Example 2: The drift velocity V_D of Hg ions in a mercury gas at E/p = 142 V/cm (mm Hg) is $V_D = 2.8 \times 10^4$ cm/sec[11].

For an electrode separation of 0.1 cm, $t = \frac{0.1}{V_D} = \frac{0.1}{2.8} \times 10^{-4} = 3.57 \times 10^{-6}$ second. L. B. Leob[12] mentioned that the growth of the Townsend discharge from a microampere to 3×10^{-4} amp at about 40 microseconds had been theoretically calculated in conformity with established constants. In operating the experiments performed by this author, the electrometer pointer always responded to the change

of gas pressure almost instantly. However, no rigorous measurements of response time were made.

III. EXPERIMENTAL TECHNIQUE

3.1 Description of Current Source and Vacuum System

In order to detect small changes in pressure, it is necessary to control the emission current to much smaller tolerance. The simplest way to achieve a constant source is to use radioactive material. But as indicated in Sec. 1.1, the existing ionization gauges using radioactive material only show current in the order of 10^{-13} ampere. Therefore, the noise due to extraneous signals makes it difficult to detect changes in such small currents.

One curie is the quantity of any radioactive isotope undergoing 3.7×10^{10} disintegrations per second. If it is possible to place one curie or more of β-ray source on the central portion of the surface of one of the electrodes; and if all the β-particles (electrons) in the hemisphere are collected by the opposite electrode (which can be practically achieved for electrodes whose spacing is much less than their diameters) then an initial current of the order of 10^{-8} amp or greater is possible. Tritium will act as an example of such a practical source. It can emit electrons of 18 Kev and has a half-life of 12.26 years. By putting this source on one of the two-inch circular copper electrodes with a separation of .20 cm as shown in Fig. 3.1, the saturation current at atmospheric pressure, with air in the chamber, is 1.8×10^{-8} ampere for V equal to 400 volts as shown in Fig. 3.2, and increases up to 10^{-5} ampere when the voltage is 1256 volts at d = 0.42 cm

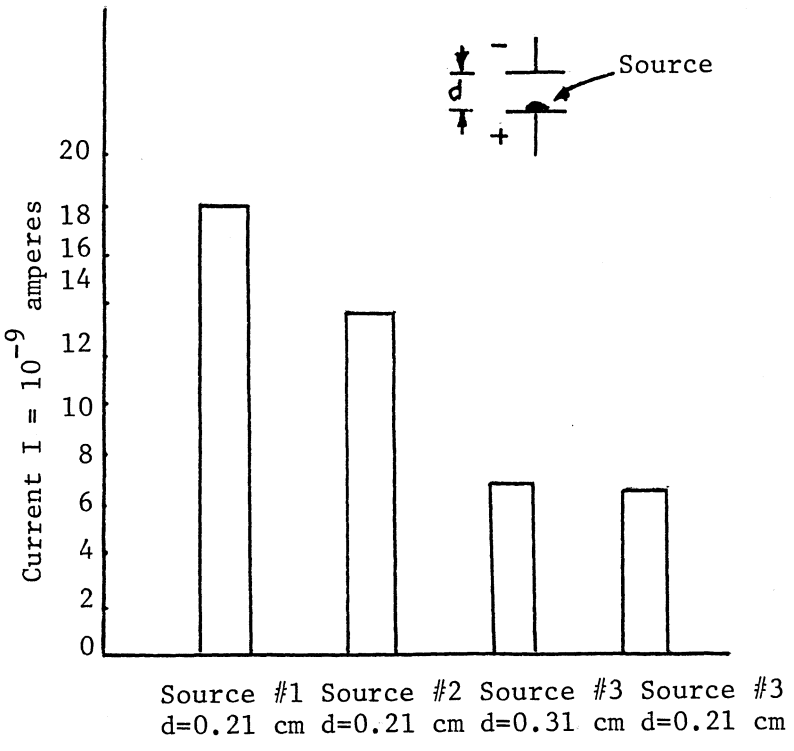
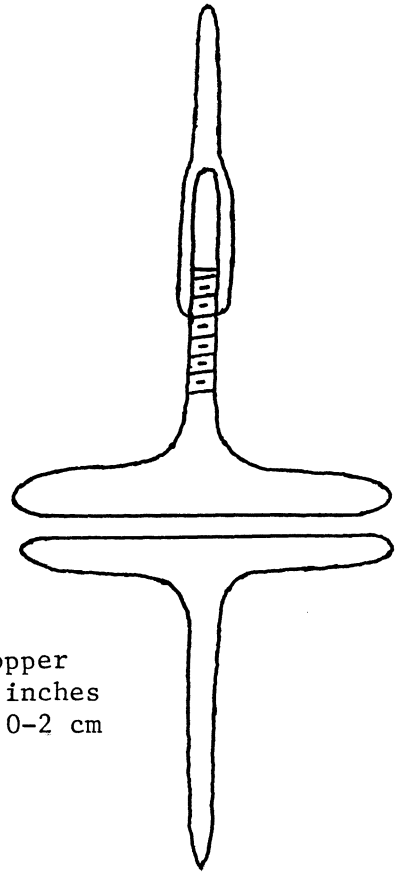


Fig. 3.2 Current Vs. Source for V=400 volts at atmospheric pressure in air



Material Copper
Diameter 2 inches
Separation 0-2 cm

Fig. 3.1 Electrodes

and p = 40 to 80 (mm Hg). (Fig. D.2g) Experiments were conducted with different quantities of tritium (Fig. 3.2), and the system behaved in the same way.

It is interesting to note that the radiation source may be placed either on the electrode of positive polarity or negative polarity without appreciably effecting the sensitivity due to the fact that the β-rays (electrons) are emitted with such high energy (18 Kev) that the electrode potential does not appreciably alter their paths. This is illustrated in the graph of experimental data, Fig. D.2m curve M_2. Almost all the experiments were done with the source placed on the positive electrode in order to make sure that currents were completely due to collision of primary electrons emitted by tritium with the gas molecules or atoms on the way to the opposite electrode. Volt ampere saturation characteristics at 71.22 (cm Hg) with a tritium source placed on the positive electrode and then on the negative electrode are shown in Fig. 3.3.

3.2 Description of Pressure Gauges Used

An oil manometer filled with Apiazon B was used to measure the differential pressure. A mechanical pressure gauge was also used to read the differential, and absolute pressure for some of the experiments. Two mercury manometers were used to read the operating pressure and also the differential pressure. One could indicate a pressure range of 0 - 12.6 (cm Hg) and another from one

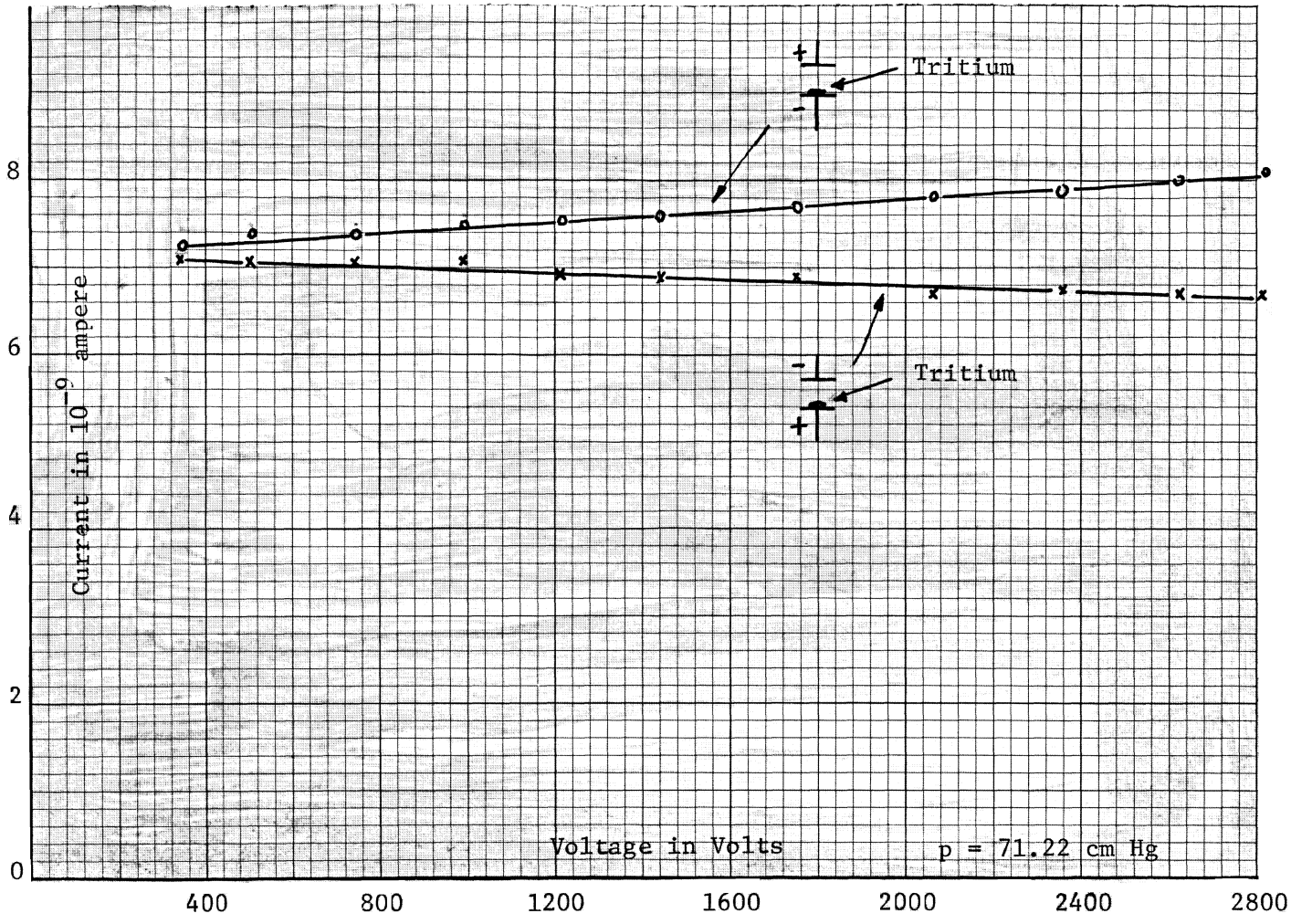


Fig.3.3 Volt-ampere characteristic for d = 0.31 cm with source #3 in air

atmospheric pressure down to 400 (mm Hg) below atmospheric pressure. The formulas for calculating the differential pressure and absolute operating pressure are shown in Appendix C.

3.3 Instrumentation

In performing the experiments, two glass vacuum systems were used. Shown in Fig. 3.4 is the second system with some improvement in the adjustment of the quantity of gas in the system. The gas chamber containing the electrodes consisted of two cups with flanges for joining them together in a vacuum tight seal. Thus, the separation of the electrodes was easily adjusted. The pressure gauges used were described in Sec. 3.2. A d.c. electrometer, Keithley Instruments Cleveland, with current range from 10^{-3} ampere through 10^{-12} ampere, was used to detect the current and current changes. A General Electric Radio Company Type 1230-A DC Amplifier and Electrometer having full scale current ranges of 10^{-3} through 10^{-13} amp. was also used in part of the experiments. A regulated high voltage power supply, Atomic Instrument Company, Model 316, with range from 0 to 3000 volts, was used to supply the d.c. electrode voltage, and calibration was made for correct reading. A Cenco-Hyvac Pump (Central Scientific Co.) which can evacuate a system to 4×10^{-4} mm Hg was used. However, the system was actually evacuated only to 0.25 mm Hg.

Electrode separation is measured by inserting thin washers of calibrated thickness between the electrodes and screwing the upper

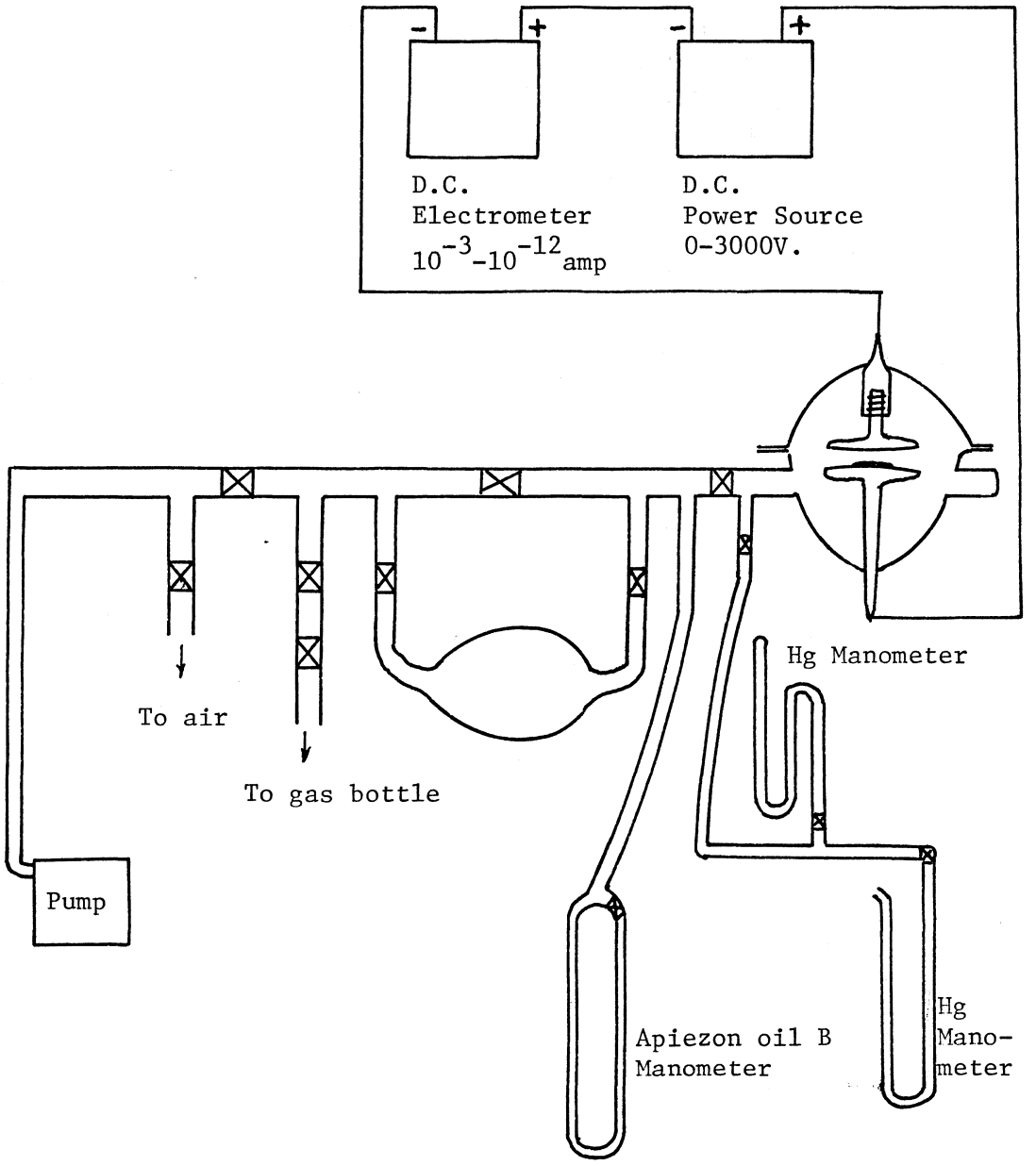


Fig.3.4 Block Diagram of Experimental Apparatus

half bell shape cup downward on the upper electrode shaft until its flange touches that of the lower cup and meanwhile the upper electrode rotates with the upper cup. Then the washers were taken out and the flanges were greased with Clevacene Light Vacuum grease to provide the seal. In handling the system, hardships were undergone in cleaning[13] and degassing the system, especially when oil and mercury manometers were used. Also, tritium, which disintegrates into hydrogen, contaminates the whole system in operation. This contamination creates some health problems in the experiments. A barometric pressure gauge was used to read the atmospheric pressure in mm Hg.

The system was set up and the experiments were carried out in the Reactor Laboratory of Physics Department, Virginia Polytechnic Institute, under the supervision of professors there.

3.4 Data Taking Procedure

1. The circuit is connected as shown in the diagram in (Fig. 3.4).
2. All valves indicated by x in a box on the diagram are opened except the inlet valves and the valve of the open end mercury manometer. The system is evacuated for 10 to 15 minutes for degassing and checking for air-tightness.
3. With the separation adjusted, current readings are taken under atmospheric pressure condition to compare the strength of the radioactive source with previous data.

4. The system is gradually evacuated while the electrometer and the pressure gauge readings are carefully monitored to determine that the pressure range is within the region of increasing current with decreasing p.
5. Evacuate the system to 0.25 mm Hg, shut off the valve of the differential oil manometer, and watch the manometer to check again whether the system is air-tight. If not, grease and clean again.
6. For a given electrode voltage the pressure is decreased until breakdown occurs. Then the pressure is increased until the lowest current is obtained. The system is then slowly evacuated in small decrements while frequent readings of pressure and current are taken. If the electrode voltage is low enough, no breakdown will occur and the current will reach a maximum with decreasing pressure and then drop again.
7. Log-log or semi-log curves are drawn for i vs. pd and slope of the i - (pd) or i - p curves is measured.

IV. EXPERIMENTAL RESULTS

Equation (2.8) defines the sensitivity as

$$S_p^i = \frac{d\ln i}{d\ln p} \qquad (2.8)$$

Thus, log-log plots of all the curves were made to ascertain whether the current was a function of pressure or pressure-separation product as expected, and meanwhile to determine the magnitude of sensitivity.

In order to show the general picture of ionization current as a function of pressure or pressure-separation product under different combinations of voltage, source strength and gas, some of the curves are plotted in a single graph. Each curve is labelled by a capital alphabet with a subscript such as A_1, B_k etc., for the individual combination of parameters as shown in Fig. 4.1a and Fig. 4.1b with source #3 in air, Fig. 4.2 with source #2 in air, and Fig. 4.3 with source #3 in krypton. The same curves are plotted on separate sheets as shown in Appendix D to facilitate the more accurate calculation of sensitivity in Sections 4.1 through 4.3 and for the comparison of sensitivities under different conditions in Section 4.5.

4.1 Sensitivity of Air at Low Potentials

Experiments were run at low voltages such as 357 V., 366 V., 610 V., 775 V., and 792 V. with different separations and source strength. Observed values of sensitivity are indicated in Table IV.I,

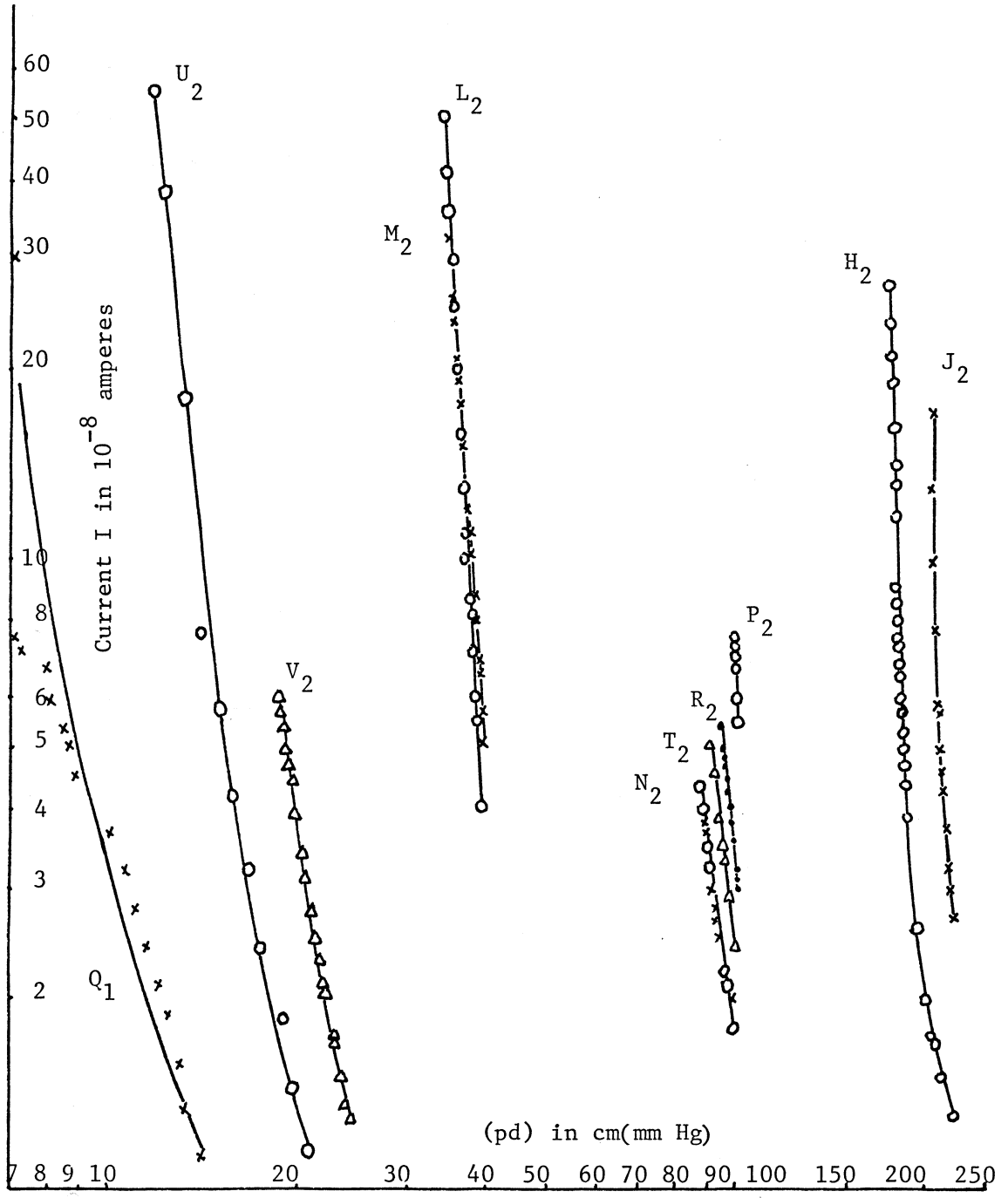


Fig. 4.1a Current Vs. pressure-separation product with source #3 in air

Curve	Q1	U2	V2	L2	M2	N2	P2	R2	T2	H2	J2
Voltage (V.)	610	1256	1256	2170	2170	2536	2810	2695	2627	6500	7000
Separation(cm)	0.42	0.42	0.21	0.31	0.31	0.14	0.14	0.14	0.14	0.31	0.31

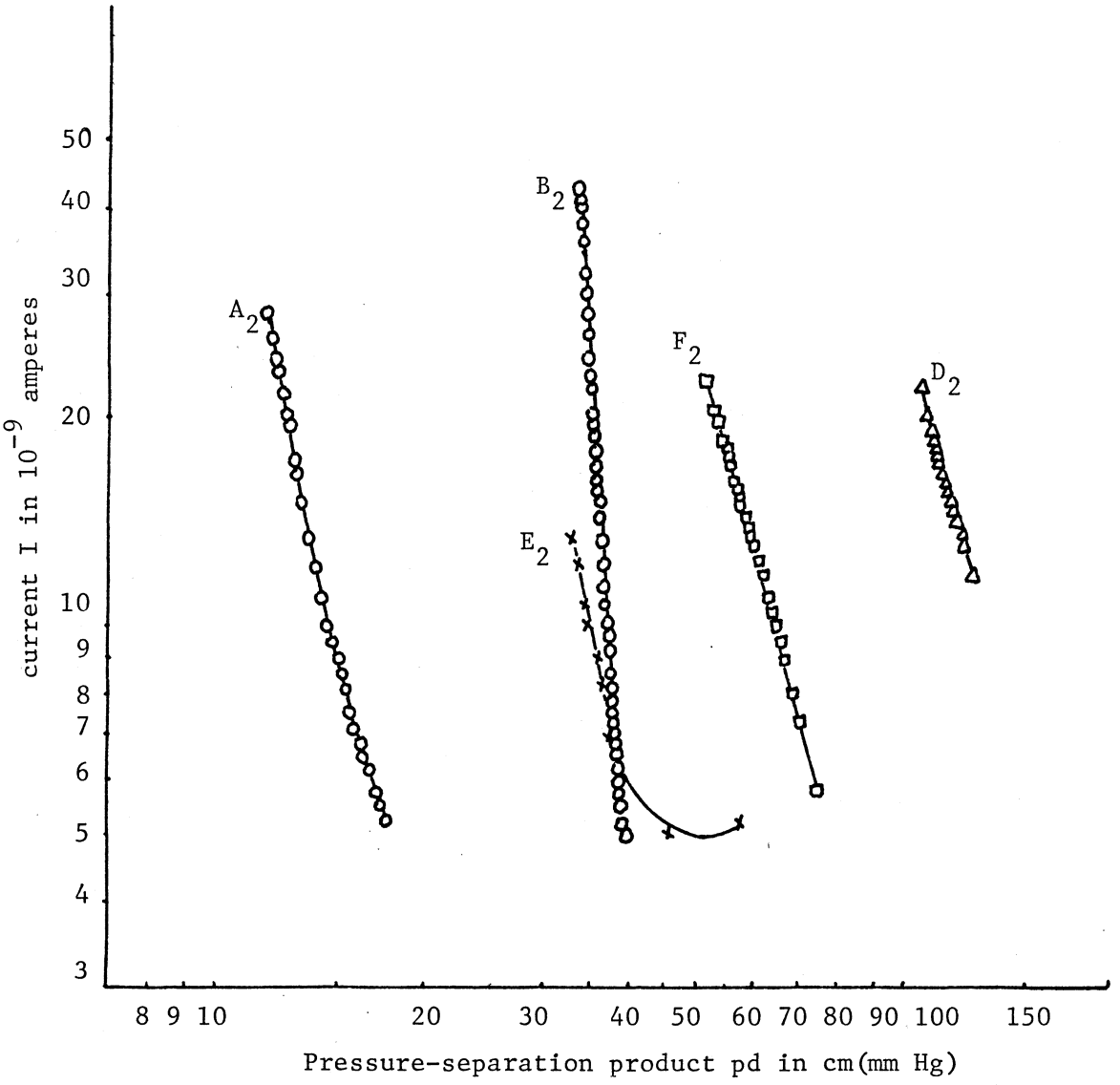


Fig. 4.1b Current Vs. pressure-separation product for air with source #3

Curve	A2	B2	E2	F2	D2
Voltage (V.)	775	2070	1164	1256	1550
Separation (cm)	0.14	0.31	0.082	0.114	0.18

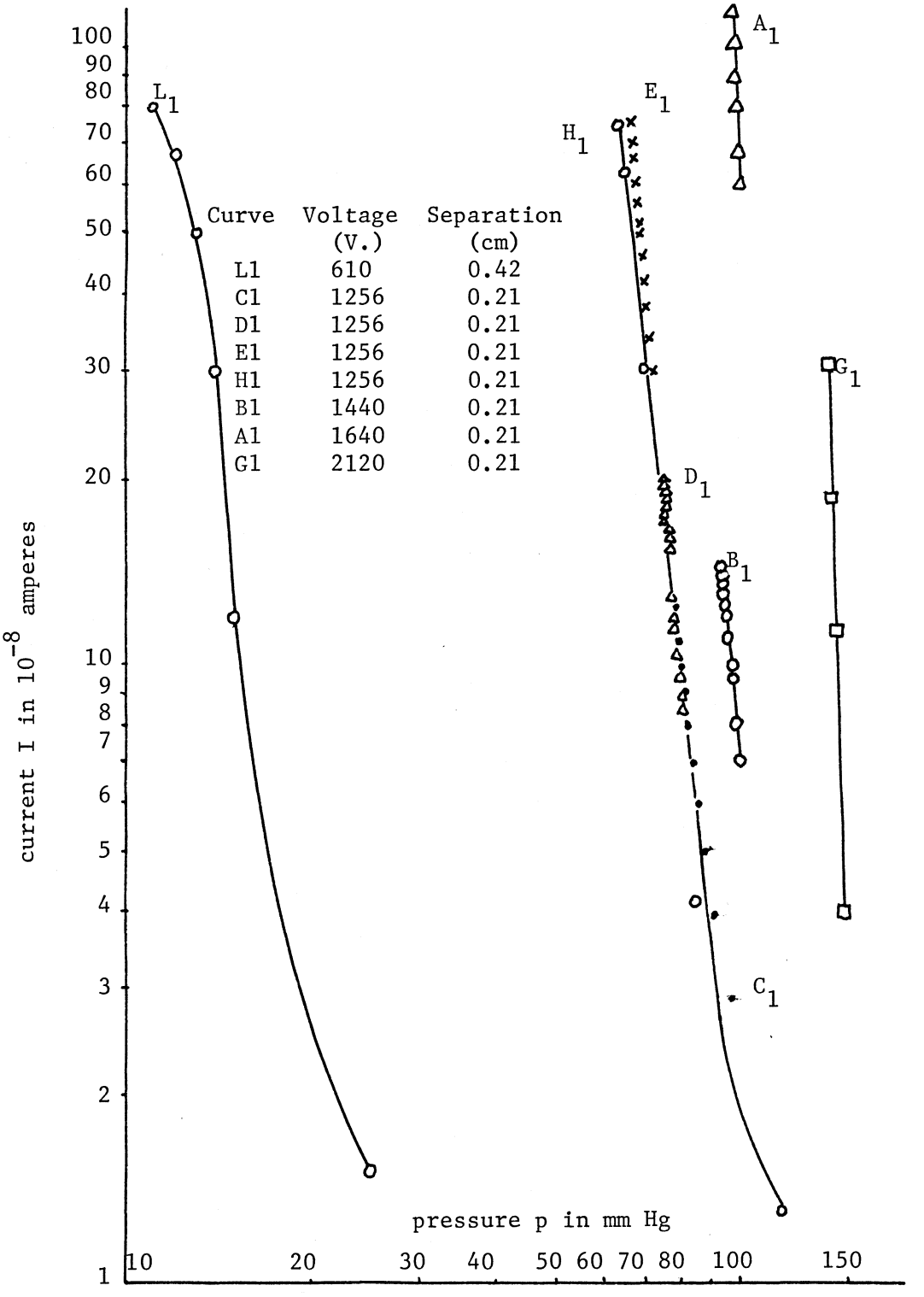


Fig. 4.2 Current Vs. Pressure with source #2 in air

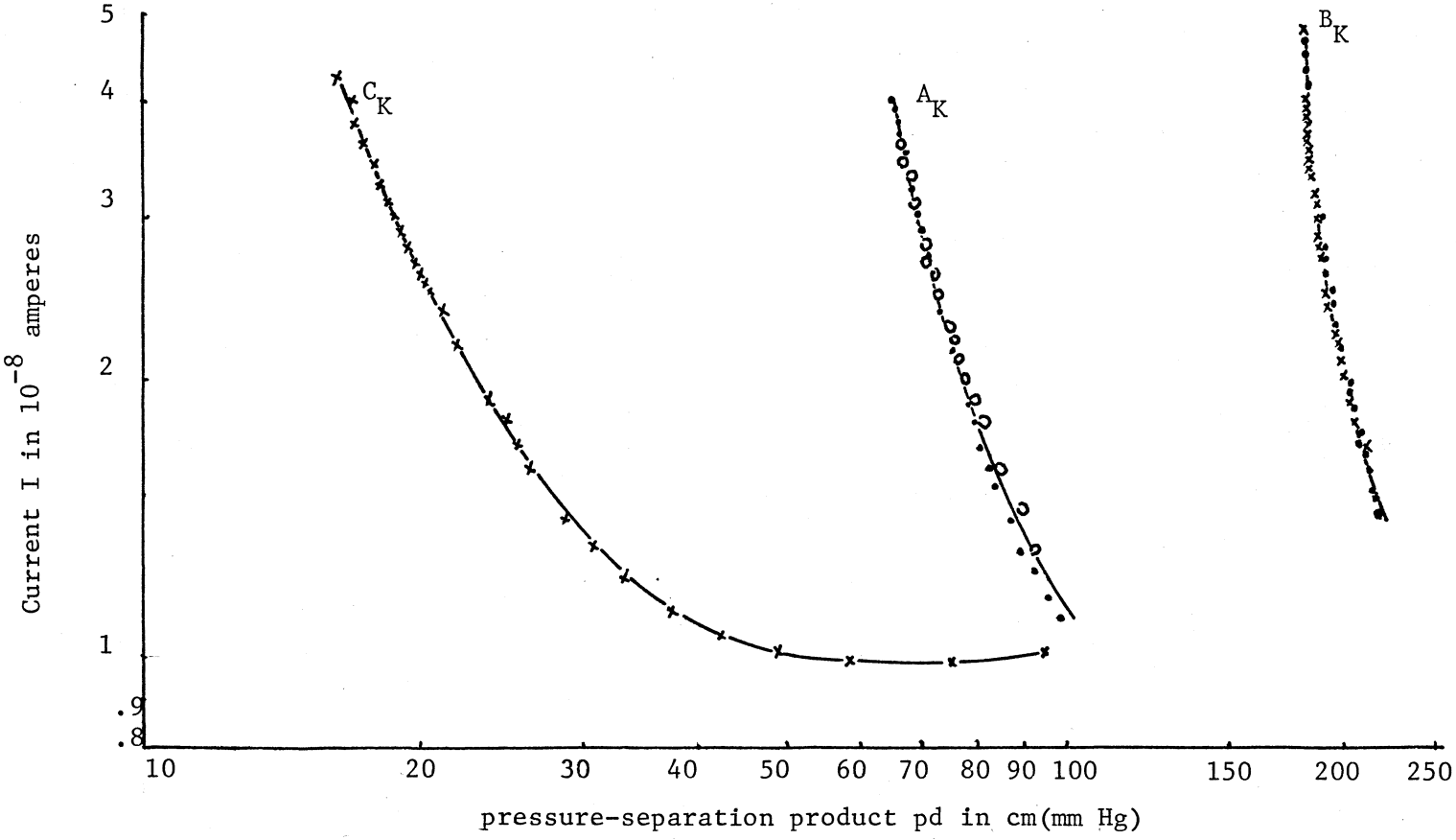


Fig. 4.3 Current Vs. pressure-separation product with source #3 in krypton

Curve	Voltage (V.)	Separation (cm)
C_K	410	0.14
A_K	872	0.14
B_K	2627	0.31

Table IV.I

Observed Values of Sensitivity of Air at Low Voltages

Fig. No. Curve No.	V (Volts)	(cm)	p (mm Hg)	E/p (V/cm mm Hg)	Source No.	S_p^i	Current Level Amp.
D.1a $\underline{B}$	357	0.14	10-50	50.8-254	#3	0.5-1.67	$2\text{-}7\times10^{-9}$
D.1a $\underline{A}$	366	0.31	4-14	84-295	#3	0.6-1.91	$2\text{-}7\times10^{-9}$
D.1b A_2	775	0.14	85-126	44-66	#3	3.05-5.62	$5\text{-}28\times10^{-9}$
D.1c L_1	610	0.42	11-25	58-132	#2	10.8	$5\text{-}55\times10^{-8}$
D.1d W_2	792	0.14	97-127	45-58.5	#3	5.86	$5\text{-}28\times10^{-9}$
D.1e Q_1	610	0.42	6.5-25	58-224	#3	3.05	$7\text{-}70\times10^{-9}$

and curves indicating current vs. pressure (i vs. p) or current vs. pressure-separation product (i vs. pd) for the calculation of sensitivity are shown in Fig. D.1.a, b, c, d and e in Appendix D.

4.2 Sensitivity of Air at High Potentials

Experiments were run with higher potentials applied across the electrodes from 1164 volts up to 11500 volts at different separations and with different quantities of sources. The observed values of sensitivity are listed in Table IV.II. Magnitude of sensitivity as high as 88 was obtained. Curves indicating current vs. pressure-separation i - pd or current vs. pressure i - p for the calculation of sensitivity are shown in Fig. D.2.a through Fig. D.2.t in Appendix D.

4.3 Sensitivity of Krypton

Krypton is 2.9 times heavier than air. Experiments were run at potentials of 410 volts, 872 volts and 2627 volts, and the observed values of sensitivity are listed in Table IV.III. Curves indicating current vs. pressure-separation i - pd for calculation of sensitivity are shown in Fig. D.3.a, b, and c in Appendix D.

4.4 Comparison of Sensitivity under Different Conditions

A comparison of sensitivity at different conditions with one variable parameter is shown in Tables IV.IVa through IV.IVe.

Table IV.IVa indicates that sensitivity increases as voltage is increased for the same separation and source strength.

Table IV.IVb indicates that generally sensitivity increases as the initial operating pressure is increased. With appropriate combination of separation and source strength, sensitivity as high as 36.4 was obtained as shown in Fig. D.2.1. (Curve G_1).

Table IV.IVc indicates that for a given voltage and source strength, the larger the separation, the higher the sensitivity. This means that the number of collisions for each primary electron is increased. However, when the separation was increased to 0.80 cm with a voltage of 11.5 KV applied, the sensitivity was still of the order of 10 and the current level was of the order 10^{-8} ampere as indicated in Fig. D.2.r curve Q_2. The ion current could be improved by placing the tritium on a spiral screen and hanging the screen midway between the electrodes. Since the tritium behaves almost the same way independent of whether it is placed opposite to the positive or negative electrode. Table IV.IVd indicates that for the same separation and electrode voltage the sensitivity is the same order of magnitude for both Krypton and air. There are gases such as Freon C-138 ($CF_2.CF_2.CF_2.CF_2$)and Perfluoro-2 Butene (C_4F_8) with molecular weight 200.04 which is almost seven times as heavy as air. If these gases behave the same way as air and krypton, then the sensitivity might be further increased by using one of them.

Table IV.IVe indicates that the stronger sources provide higher sensitivities for the same voltage and separation.

Table IV.II

Sensitivity of Air at High Potentials

Figure No. Curve No.	V Volts	d cm	p mm Hg	E/p V/cm mm Hg	Source No.	S_p^i	Current Level 10^{-8} Amp.
D.2.a E2	1164	0.082	400-450	31.5-35.5	#3	4.8	.8-1.3
D.2.b C1	1256	0.21	78-95	63-77	#2	10.1	3-14
D.2.c H1	1256	0.21	60-85	70-100	#2	9.5	10-70
D.2.d D1	1256	0.21	60-83	72-100	#2	9.3	10-50
D.2.e E1	1256	0.21	66-72	83-91	#2	11.7	30-75
D.2.f F2	1256	0.114	450-620	17.9-24.5	#3	2.59	$.7\text{-}2.3_3$
D.2.g M1	1256	0.42	40-80	37.5-75	#2	14.9	$.1\text{-}10^3$
D.2.h B1	1440	0.21	93-100	68.5-74	#2	10.5	7-14
D.2.i D2	1550	0.18	510-680	12.7-17	#3	1.57-5.36	1.0-2.6
D.2.j A1	1640	0.21	97-100	78-81	#2	24	6-11
D.2.k B2	2070	0.31	108-125	53.1-62	#3	15	.5-4.2
D.2.l G1	2120	0.21	139-150	67-72	#2	36.4	5-30
D.2.m L2	2170	0.31	110-128	55-63.8	#3	17.3	.6-1.7
D.2.m M2	2170	0.31	110-128	55-63.8	#3	13.4	.6-1.7
D.2.n N2	2536	0.14	630-712	25.4-28.7	#3	4.32-9.7	2-4.5
D.2.n T2	2627	0.14	640-712	26.4-29.4	#3	6.92-8.8	2.5-5
D.2.n R2	2695	0.14	680-712	27.1-28.4	#3	9.2	3-5
D.2.n P2	2810	0.14	702-712	28.2-28.6	#3	29	5-7.5
D.2.q H2	6500	0.31	566-711	29.6-37.2	#3	49	2-27
D.2.q J2	7000	0.31	661-711	31.6-34	#3	88	2.5-17
D.2.r Q2	11500	0.80	529-711	20.3-27.3	#3	10.2	2-12
D.2.s U2	1256	0.42	30-60	50-100	#3	10.6	1.0-50.0
D.2.t V2	1256	0.21	89-115	52-67	#3	6.0	1.5-6.0

Table IV.III

Sensitivity of Krypton

Fig. No. Curve No.	V (Volts	d (cm)	p mm Hg	E/p V/cm mm Hg	Source No.	S_p^i	Current Level Amp.
D.3.a C_k	410	0.14	117-150	19.6-25	#3	3.39	$2\text{-}4.5\times10^{-8}$
D.3.b A_k	872	0.14	460-703	8.8-13.6	#3	4.76	$1\text{-}4\times10^{-8}$
D.3.c B_k	2627	0.31	580-705	12-14.6	#3	10.4	$1.5\text{-}4.7\times10^{-8}$

Table IV.IVa

Sensitivity and Voltage (Air and Krypton)

d = 0.14 cm Source #3 AIR			d = 0.31 cm Source #3 AIR			d = 0.21 cm Source #2 AIR		
V Volts	S_p^i	Fig. No. Curve No.	V Volts	S_p^i	Fig. No. Curve No.	V Volts	S_p^i	Fig. No. Curve No.
775	3.05-562	D.1.b, A_2	2070	15.0	D.2.k, B_2	1256	9.3	D.2.d, D_1
792	5.86	D.1.d, W_2	2170	17.3	D.2.m, L_2	1256	9.5	D.2.c, H_1
2536	9.7	D.2.n, N_2	6500	49.0	D.2.q, H_2	1256	10.1	D.2.b, C_1
2810	29.0	D.2.n, P_2	7000	88	D.2.q, J_2	1256	11.7	D.2.e, E_1
357	1.67	D.1.a, B	366	1.91	D.1.a, $\overline{A}$	1440	10.5	D.2.h, B_1
						1640	24	D.2.j, A_1
						2120	36.4	D.2.1, G_1
d = 0.42 cm Source #2 AIR			d = 0.42 cm Source #3 AIR			d = 0.14 cm Source #3 Krypton		
V Volts	S_p^i	Fig. No. Curve No.	V Volts	S_p^i	Fig. No. Curve No.	V Volts	S_p^i	Fig. No. Curve No.
610	10.8	D.1.c, L_1	610	3.05	D.1.e, Q_1	410	3.39	D.3.a, C_k
1256	14.9	D.2.g, M_1	1256	10.6	D.2.s, U_2	872	4.76	D.3.b, A_k

Table IV.IVb

Sensitivity and Pressure Range (Air)

d = 0.14 cm Source #3			d = 0.31 cm Source #3			d = 0.21 cm Source #2		
p mm Hg	S_p^i	Fig. No. Curve No.	p mm Hg	S_p^i	Fig. No. Curve No.	p mm Hg	S_p^i	Fig. No. Curve No.
85-126	5.62	D.1.b, A_2	105-125	15	D.2.k, B_2	66-72	11.7	D.2.e, E_1
97-127	5.86	D.1.e, W_2	110-128	17.3	D.2.m, L_2	60-85	9.5	D.2.c, H_1
630-715	9.7	D.2.n, N_2	110-128	13.4	D.2.m, M_2	60.5-83	9.3	D.2.d, D_1
640-715	8.8	D.2.n, T_2	566-711	49	D.2.g, H_2	78-95	10.1	D.2.b, C_1
680-715	9.2	D.2.n, R_2	661-711	88	D.2.g, J_2	93-100	10.5	D.2.h, B_1
702-712	38.6	D.2.n, P_2	4-14	1.91	D.1.a, $\overline{A}$	97-100	24	D.2.j, A_1
10-50	1.67	D.1.a, B				137-150	36.4	D.2.1, G_1

d = 0.42 cm Source #3		
p mm Hg	S_p^i	Fig. No. Curve No.
6.5-25.0	3.05	D.1.e, Q_1
39-60	10.6	D.2.s, U_2

Table IV.IVc

Sensitivity and Separation (Air and Krypton)

V = 1256 Volts Source #2 AIR			V = 1256 Volts Source #3 AIR			V = 872^{V} - 2627^{V} Source #3 Krypton		
d cm	S_p^i	Fig. No. Curve No.	d cm	S_p^i	Fig. No. Curve No.	d cm	S_p^i	Fig. No. Curve No.
0.21	9.3-11.7	D.2.b, C_1	0.21	6.0	D.2.1, V_2	0.14 (872V)	4.76	D.3.b, A_k
		D.2.c, H_1						
		D.2.d, D_1	0.42	10.6	D.2.s, U_2	0.31 (2627V)	10.4	D.3.c, B_k
		D.2.e, E_1						
0.42	14.9	D.2.g, M_1						

Table IV.IVd

Sensitivity and Gas

Gas (Molecular Weight)	V Volts	d cm	S_p^i	Fig. No. Curve No.
Air (28.96)	775	0.14	5.62	D.1.b, A_2
Krypton (82,92)	872	0.14	4.76	D.3.b, A_k
Air	2170	0.31	17.3	D.2.m, L_2
Krypton	2627	0.31	10.4	D.3.c, B_k
Air	2627	0.14	8.8	D.2.n, T_2

Table IV.IV.e

Sensitivity and Source Strength (AIR)

V = 1256 Volts d = 0.42 cm			V = 1256 Volts d = 0.21 cm			V = 610 Volts d = 0.42 cm		
Source No.	S_p^i	Fig. No. Curve No.	Source No.	S_p^i	Fig. No. Curve No.	Source No.	S_p^i	Fig. No. Curve No.
#2	14.9	D.2.g, M_1	#2	9.3-11.7	D.2.b, C_1	#2	10.8	D.1.c, L_1
#3	10.6	D.2.s, U_2			D.2.c, H_1			
					D.2.d, D_1	#3	3.05	D.1.e, Q_1
					D.2.e, E_1			
			#3	6	D.2.t, V_2			

4.5 Comparison of the Observed Values with Calculated Values and Comments

In Table IV.V.1 the data for Curves $\overline{A}$, B_2, W_2 and $\overline{B}$ are listed. Constants A and B are calculated for Curves $\overline{A}$ and $\overline{B}$ according to the formula (Sec. 2.3) $B = V(\text{volts}/(pd)_{imax}$ [cm (mm Hg)]

$$\frac{A}{B} = S_p^i\Big]_{max}/0.309\ V$$

where V, $(pd)_{imax}$, and $S_p^i\Big]_{max}$ are observed values. From the calculated values of A and B, the value of pd for $S_p^i\Big]_{max}$ is calculated according to the relation (Sec. 2.3).

$$(pd)_{S_p^i\Big]_{max}} \frac{B}{V} = 2.62$$

The observed $^{(pd)}S_p^i\Big]_{max}$ is 2.48 [cm (mm Hg)] for Curve $\overline{A}$, and 3.59 for Curve $\overline{B}$. The calculated values of $^{(pd)}S_p^i\Big]_{max}$ for Curves $\overline{A}$ and $\overline{B}$ are 2.45 and 3.14 respectively.

Since A and B remain essentially constant over a certain region of E/p, if d is maintained constant at 0.31 cm and the voltage is increased from 366 volts to 2010 volts, then the maximum sensitivity will be increased from 1.91 at p = 8.1 mm Hg to 10.5 at 44.5 mm Hg. However, Curve B_2 indicates that with d = 0.31 cm and V = 2070 volts, breakdown occurs at p = 108.6 mm Hg far above the point for $S_p^i\Big]_{max}$ to occur, while the observed value of S_p^i for Curve B_2 is 15. If, with d = 0.14 cm, the voltage is increased from 357 to 790 volts, the maximum sensitivity will be increased from 1.67 to 3.66 at p = 54 mm Hg. However, Curve W_2 indicates that with d = 0.14 cm and V = 792 volts, breakdown occurs at p = 98.5 mm Hg, far above the point for

Table IV.VI

Comparison of Calculated Values with Observed Values for Air

Curve No.	$\overline{A}$ Fig. D.1.b	B2 Fig. D.2.k	$\overline{B}$ Fig. D.1.a	W2 Fig. D.1.d
V (Volts)	366	2070	357	792
d (cm)	0.31	0.31	0.14	0.14
E (V/cm)	1180	6680	2560	5680
p (mm Hg)	4-14	105-125	10-50	97-127
E/p [V/cm(mm Hg)]	84-295	53-63.8	51-256	45-58.6
Source No.	#3	#3	#3	#3
$(pd)_{imax}$ (observed) [cm(mm Hg)]	0.935		1.2	
B (calculated) V/[cm(mm Hg)]	391		297	
$(pd)_{S^i_{pmax}}$ (observed) [cm(mm Hg)]	2.48		3.59	
S^i_{pmax} (observed)	1.91	15	1.67	5.86
$\frac{A}{B}$ (calculated) (1/volts)	0.0169		0.0151	
A(calculated) [1/cm(mm Hg)]	6.6		4.5	
$(pd)_{S^i_{pmax}}$ (calculated) [cm(mm Hg)]	2.45		3.14	
Breakdown pressure (mm Hg)		108.6		98.5

Existing Data for Constants A and B for Air

A $\frac{1}{\text{cm (mm Hg)}}$	B $\frac{V}{\text{cm (mm Hg)}}$	Range of Validity $\frac{E}{p}$ [(V/cm(mm Hg)]
15	365	100-800
8.6	254	30-180

$S_p^i\Big]_{max}$ to occur. The observed value of S_p^i for Curve W_2 is 5.86, Curve P_2 (Fig. D.2.n) indicates for V = 2810 volts S_p^i is increased to 29.

Equation (2.20) gives the appropriate value of (pd) for maximum sensitivity without breakdown. With A = 6.6 the proper range to achieve maximum S_p^i without breakdown for (pd) is either between 1.9 and 9.6 cm (mm Hg) or is less than 1.9 cm (mm Hg). The range of pd for curve $\overline{A}$ is from 1.24 to 4.35 cm (mm Hg); therefore, the maximum sensitivity occurs without breakdown. But for Curve B_2, the range of pd is from 32.5 to 38.7 cm (mm Hg), therefore, the pressure cannot be reduced to the point for $S_p^i\Big]_{max}$ before breakdown.

Since the basic equation such as Eq. (2.4) is approximate and data for A, B, and γ are obtained from past experiments, the discussion can be based only on general trend. The best way to accomplish an optimum transient velocity gauge is to test that particular device for the most appropriate gas and power source available to determine the best operating pressure and separation for the highest sensitivity.

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

There are four items as conclusion to be drawn from the experiment performed by the author:

1. Sensitivity of a value of eighty-eight was obtained at an operative pressure near atmospheric pressure and with an electrode voltage of 7 kilovolts applied. The fractional current change, $\frac{\Delta i}{i}$, depends more on the pressure change, Δp, than on the initial operating pressure, p.
2. An operating current of the order of 10^{-5} ampere may be obtained with a tritium source of less than one curie. Both sensitivity and current levels increased with increased quantity of radioactivity material.
3. Since there is an optimum combination of separation, source strength, voltage applied, gas used and operating pressure for best sensitivity and current level, and since tritium may be either placed on an anode or a cathode without appreciably changing the sensitivity, a spiral zirconium screen soaked with tritium and hung midway between two larger circular electrodes will provide a larger separation, which, in turn, will let the system sustain a higher voltage without breakdown. Therefore, greater sensitivity at an acceptable operating voltage is achievable.

4. For an air chamber of 3 inches in length with a time constant of 10 seconds under a shock load of 500 g's $\frac{\Delta p}{p}$ will be 0.000227 ($= \frac{500 \times 32.2 \times 0.002378 \times \frac{3}{12} \times \frac{1}{144}}{14.7 \ \# \ in^{-2} \times 2 \times 10}$. If the sensitivity of the system is 50, then $\frac{\Delta i}{i}$ will be 0.01135. If the gas used is 5 times heavier than air, then $\frac{\Delta i}{i}$ will be 0.05675. If the operating current is 10^{-4} ampere, Δi will be 5.68×10^{-6} ampere or 5.68 microamperes. If the sensitivity is 100, then $\frac{\Delta i}{i}$ will be 0.114. (Assume $\Delta t/T = 1/10$)

5.2 Recommendation

As a result of the experiment performed by the author, it is recommended that the following items be given further consideration:

1. Further experiments to determine the best combination of source, strength, separation, gases and electrode voltage, as stated in Sec. 5.1.3.
2. Design of low noise circuits for detecting current changes.
3. Construction and testing of a simple model subject to shock.
4. Further investigation of the relation between $\frac{\Delta i}{i}$ and Δp.

REFERENCES CITED

1. Glenn L. Mellen, "Radium-Type Vacuum Gauge," Electronics, April, 1946.
2. R. H. Vacca, "Recent Advances in the 'Alphatron' Vacuum Gauge," Vacuum Symposium Transactions, 1956.
3. J. R. Roehrig and G. F. Vanderschmidt, "Advances in the Design of Vacuum Gauges Using Radioactive Materials," Vacuum Symposium Transactions, 1959.
4. Same as in (3).
5. A. Von Engel, Ionized Gases, Second Edition, 1965, p. 180.
6. E. Nasser, Notes on High Voltage Engineering, and A. Von Engel, Ionized Gases, Second Edition, 1965, p. 181.
7. L. B. Loeb, Basic Processes of Gaseous Electronics, Second Edition, 1965, p. 736.
8. A. Von Engel, Ionized Gases, Second Edition, 1965, p. 195.
9. E. Nasser, Notes on High Voltage Engineering, 1966.
10. A. Von Engel, Ionized Gases, Second Edition, 1965, p. 124.
11. A. Von Engel, Ionized Gases, Second Edition, 1965, p. 119.
12. L. B. Loeb, Gaseous Electronics, 1961, p. 753.
13. Andrew Guthrie, Vacuum Technology, Sec. 9.2, p. 263; Sec. 9.5, p. 271; and Sec. 9.7, p. 274, 1963.

ADDITIONAL REFERENCES

1. K. W. Yee, R. J. Carpenter, "Regulation of Ionization Gauge Emission Current to better than 0.05%," Rev. Sci. Inst., V. 34, no. 10, Oct., 1963, p. 1101-3.
2. H. Blank, K. Petzold, "Applicability of Bayand-Alpert Gauge with Conducting inner wall for pressure measurement over range 1 - 10^{-11} Torr." Vacuum 15 n 3 March, 1965, p. 127-34.
3. W. G. Brombacher, "Survey of Ionization Vacuum Gauge and Their Performance Characteristics," U.S. Bur. Standards Tech. Note 298, February 3, 1967, 62p.
4. W. P. Overbeck, F. A. Meyer, "Grid Current Control for the Ionization Gauge," R.S.I. 287, 1934.
5. L. N. Ridenour, C. W. Lampson, "Thermionic Control of an Ionization Gauge," R.S.I. 162, 1937.
6. H. L. Dunegan, C. A. Tatro, "Passive Pressure Transducer Utilizing Acoustic Emission," R.S.I. 1145, August, 1967.
7. Clifton B. Sibley and Jonathan R. Roebrig, "Wide Range Vacuum Gauge," Electronics, p. 176, November, 1953.

APPENDIX A

Relation Between Transient Velocity and Pressure Change

In Fig. 2.1 the chamber is filled with a gas of density ρ_o at pressure p_o. After being subject to a step change of acceleration, "a ", having a duration, "Δt ", due to the restriction inside the chamber the gas will take time (several time constants T) to change its pressure from p_o to a steady-state value of $p_o + \Delta p'$.

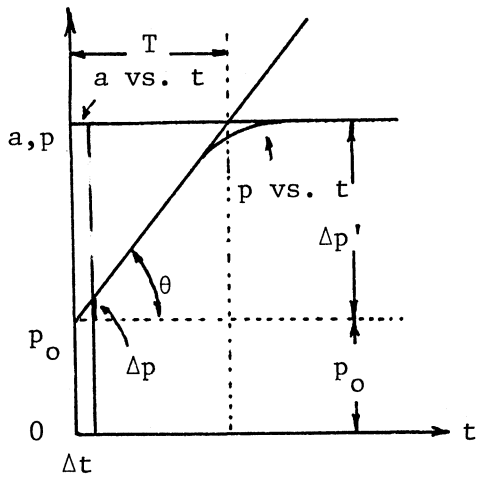


Fig. A.1

In Appendix B it is shown that Δp, the pressure change, is proportional to "a " for a chamber of given length and gas density. The graph of acceleration and pressure vs. time is shown in Fig. A.1. For a time duration of Δt much less than T, the pressure change will be

$$\Delta p = (\Delta t) \quad (\tan \theta) \tag{A.1}$$

and

$$\tan \theta = \Delta p'/T \propto a/T \tag{A.2}$$

$$\Delta p \propto (\Delta t)a/T = \Delta \upsilon/T \tag{A.3}$$

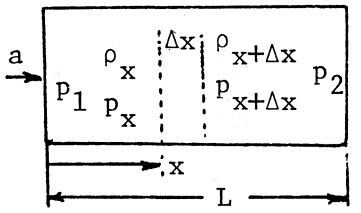
Therefore, for a given acceleration "a" and a given time of interaction Δt, Δp is defined. In other words, $\Delta \upsilon$ may be measured in terms of pressure change Δp since they are proportional. If the initial velocity of the chamber along the direction of acceleration is v_o, then

the transient velocity of the chamber is $v_o + \Delta v$. If v_o is zero, then Δv is the transient velocity of the chamber.

APPENDIX B

Relation Between Pressure Change and Acceleration

Assume that a cylindrical box of cross-sectional area "A" and length "L" is filled with a gas of density ρ_o at pressure p_o, and this chamber is subject to a shock load of acceleration "a" (Fig. B.1). Also assume that all the gas molecules inside the box gain acceleration--"a" with respect to the case of the box.



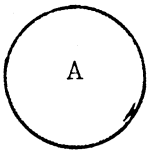


Fig. B.1

For the case of no restriction inside the chamber, the pressure and density at x are p_x and ρ_x, and at $(x + \Delta x)$, $p_{(x + \Delta x)}$ and $\rho_{(x + \Delta x)}$ respectively. Assume that the gas density ρ_x is uniform all over the cross-section at x, then

$$(\Delta x)A\ \rho_x a = [p_x - p_{(x + \Delta x)}]A \tag{B.1}$$

$$A(p_1 - p_2) = \int_o^L \rho_x\ Aadx$$

$$= Aa \int_o^L \rho_x\ dx \tag{B.2}$$

and $$2\Delta p' = p_1 - p_2 = \frac{a}{A} \int_o^L A\rho_x\ dx \tag{B.3}$$

where $\Delta p'$ is the pressure change at either end of the chamber due to acceleration "a."

Since the mass of the gas contained inside the chamber is of the same finite quantity both before and after being hit and is equal $\rho_o LA$, we have

$$\int_0^L A\,\rho_x\,dx = \rho_o LA \tag{B.4}$$

$$\Delta p' = (p_1 - p_2)/2$$

$$= a\rho_o L/2 \tag{B.5}$$

When there is a restriction inside the chamber and if the pressure change is enough to cause an appreciable ionization current change and yet is not enough to cause an appreciable density change, then, in carrying out the integration of (B.3), the density of the gas may be considered constant and uniform all over the entire chamber both before and after the shock load is applied.

From Eq. (B.3) we have

$$2\Delta p' = a\int_0^L \rho_x\,dx = a\,\rho_o\int_0^L dx$$

$$\Delta p' = \frac{1}{2}\,a\,\rho_o\,L \tag{B.6}$$

which is the same as in Eq. (B.5).

From Fig. A.1 we have

$$\Delta p = \frac{\Delta t}{T}\,\Delta p'$$

$$= \frac{\Delta t}{T}\,\frac{a}{2}\,\rho_o\,L \tag{B.7}$$

$$\Delta p \propto a\rho_o L \tag{B.8}$$

for a given chamber of time constant T and a given time of interaction $\Delta t \ll T$, where Δp is the pressure change at the end of time duration Δt.

APPENDIX C

Differential Pressure Gauge

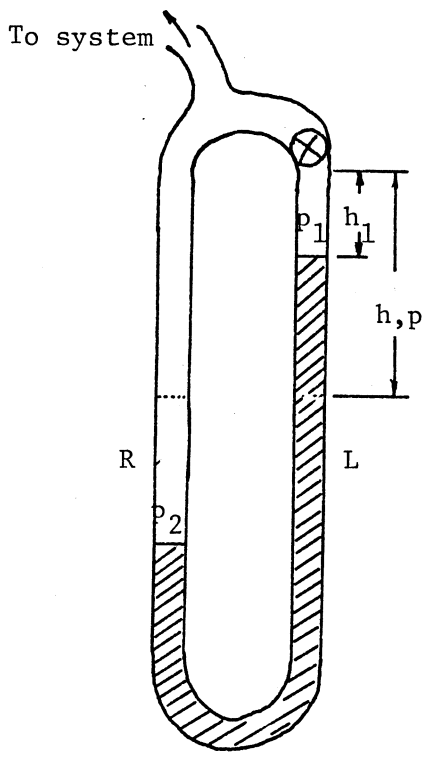


Fig. C.1

As shown in Fig. C1, when the system is evacuated to a certain operating pressure p, shut off the valve. The oil levels of both legs are equal. After some gas is fed into the system, the oil level in the left leg rises while that in the right leg is lowered.

$$p_1 h_1 = ph \qquad (C.1)$$

$$p_2 = p_1 + 2(h - h_1)$$

$$= \frac{h}{h_1} p + 2(h - h_1) \qquad (C.2)$$

where p_1, p_2 and p are in cm of the oil being used.

The specific gravity of oil Apiezon B is 0.873.

Example: At an initial operating pressure p of 100 mm Hg, the valve of the oil manometer is shut off and h is 40 cm. After some gas is introduced into the system, the oil level in the left leg is raised to a point where h_1 reads 38 cm. The pressure of the gas in this system is increased from p to p_2 which is calculated as follows:

$$p_2 = \frac{40}{38} \times 10.0 \times \frac{13.6}{0.873} + 2(40 - 38)$$

$$= 1.052 \times 10.0 \times 15.6 + 4$$

$$= 168.2 \text{ cm oil}$$

or 108 mm Hg.

APPENDIX D

Current vs. Pressure or Pressure-Separation Product for Calculation of Sensitivity

In this Appendix curves for current i vs. pressure p or pressure-separation product pd for different combination of voltage, source strength and gas are plotted in separate sheets to facilitate the calculation of sensitivity. Some data were taken at different runs with the same combination of parameters.

Fig. D.1.a through Fig. D.1.e are curves for air at low voltages from 357 V. to 792 V. Fig. D.2.a through Fig. D.2.t are curves for air at high voltages from 1164 V. to 11500 V. Fig. D.3.a through Fig. D.3.c are curves for krypton at voltages of 410 V., 872 V. and 2627 V. Each curve is given the same label as indicated in Fig. 4.1 through Fig. 4.3.

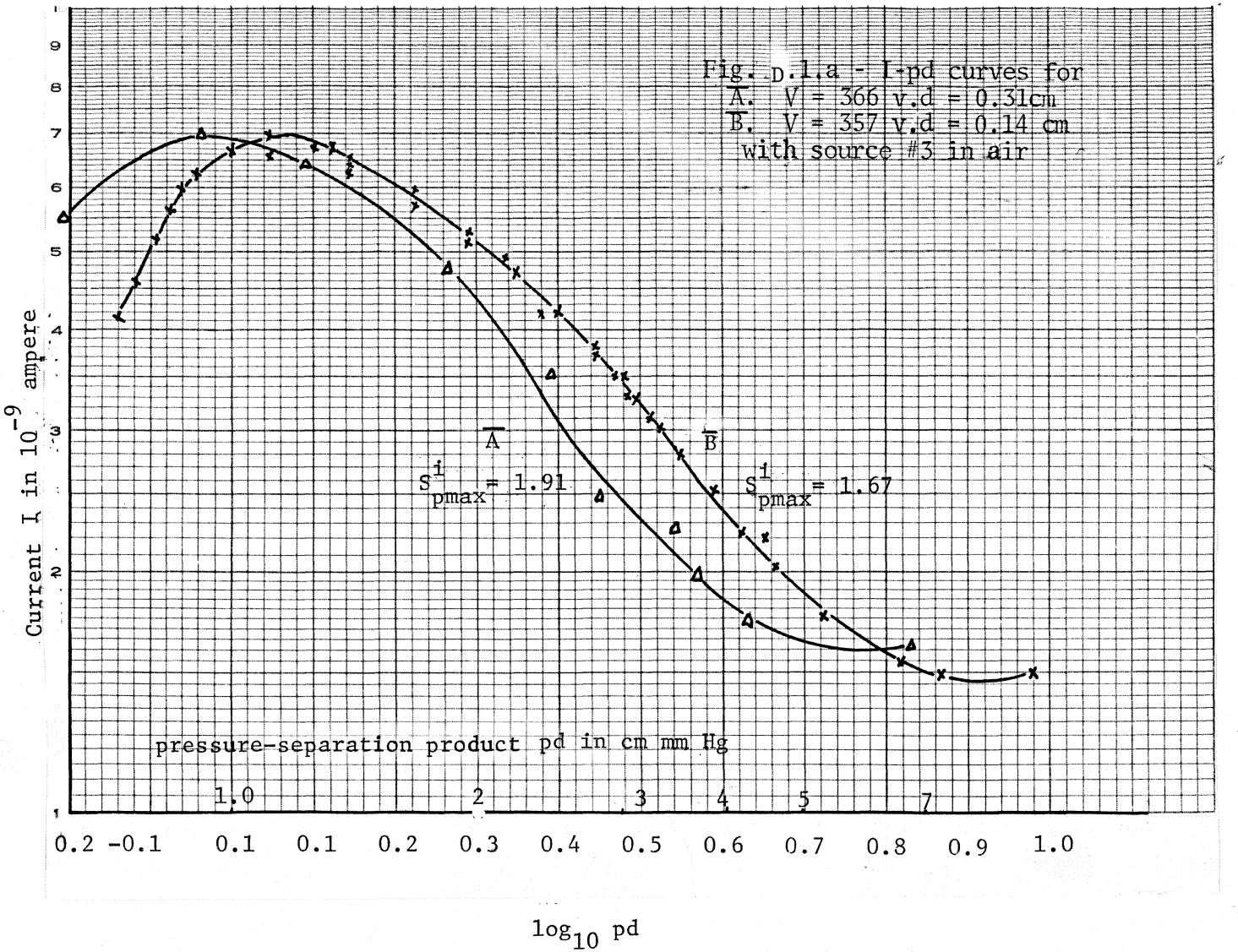


Fig. D.1.a - I-pd curves for
A. V = 366 v.d = 0.31cm
B. V = 357 v.d = 0.14 cm
with source #3 in air
Current I in 10^{-9} ampere
A
B
S^i_{pmax} = 1.91
S^i_{pmax} = 1.67
pressure-separation product pd in cm mm Hg
1.0
2
3
4
5
7
0.2 -0.1 0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
$\log_{10}$ pd

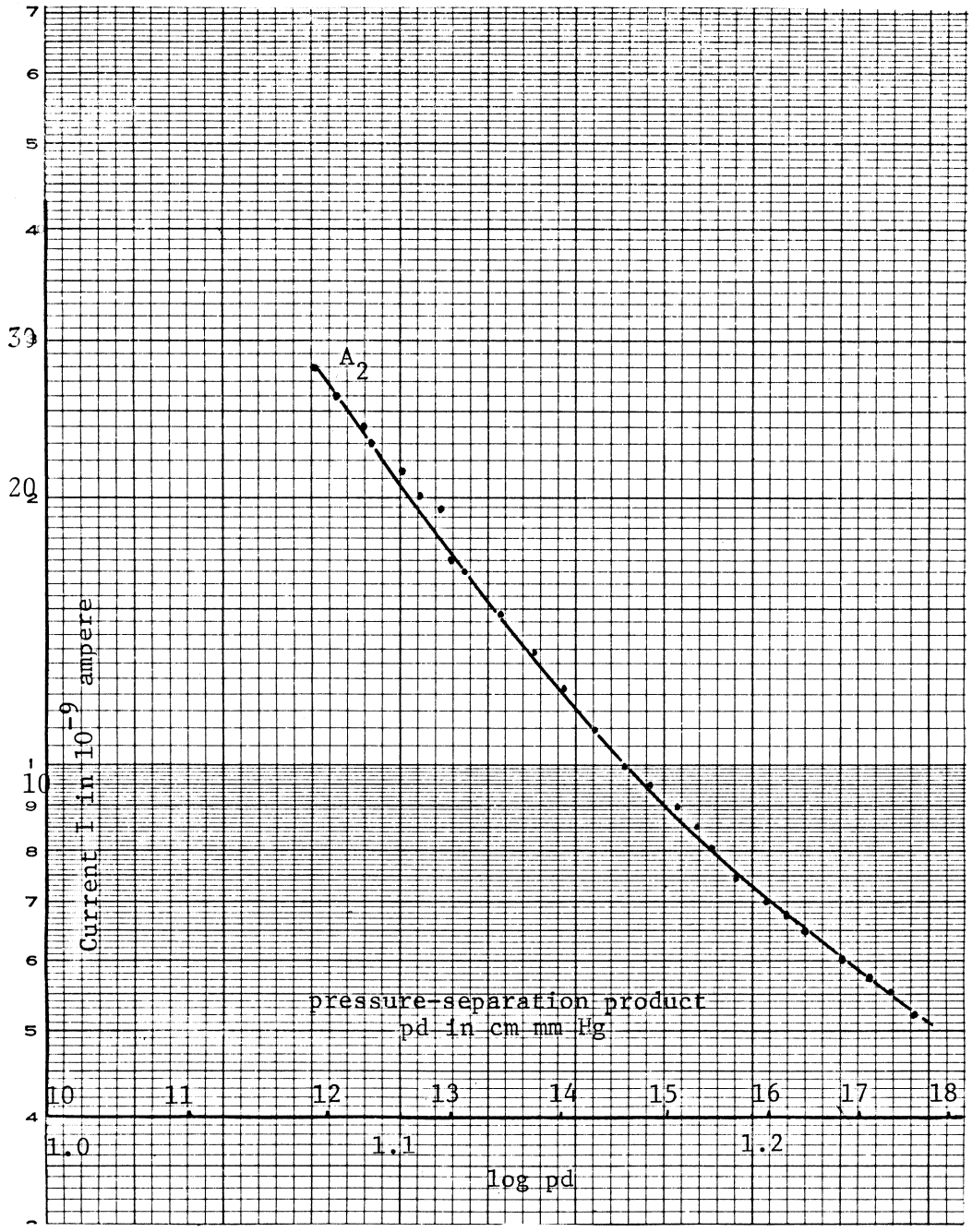


Fig.D.1b i-pd curve for V=775V. d=0.14 cm with source #3 in air $S_p^i = 3.05 - 5.62$

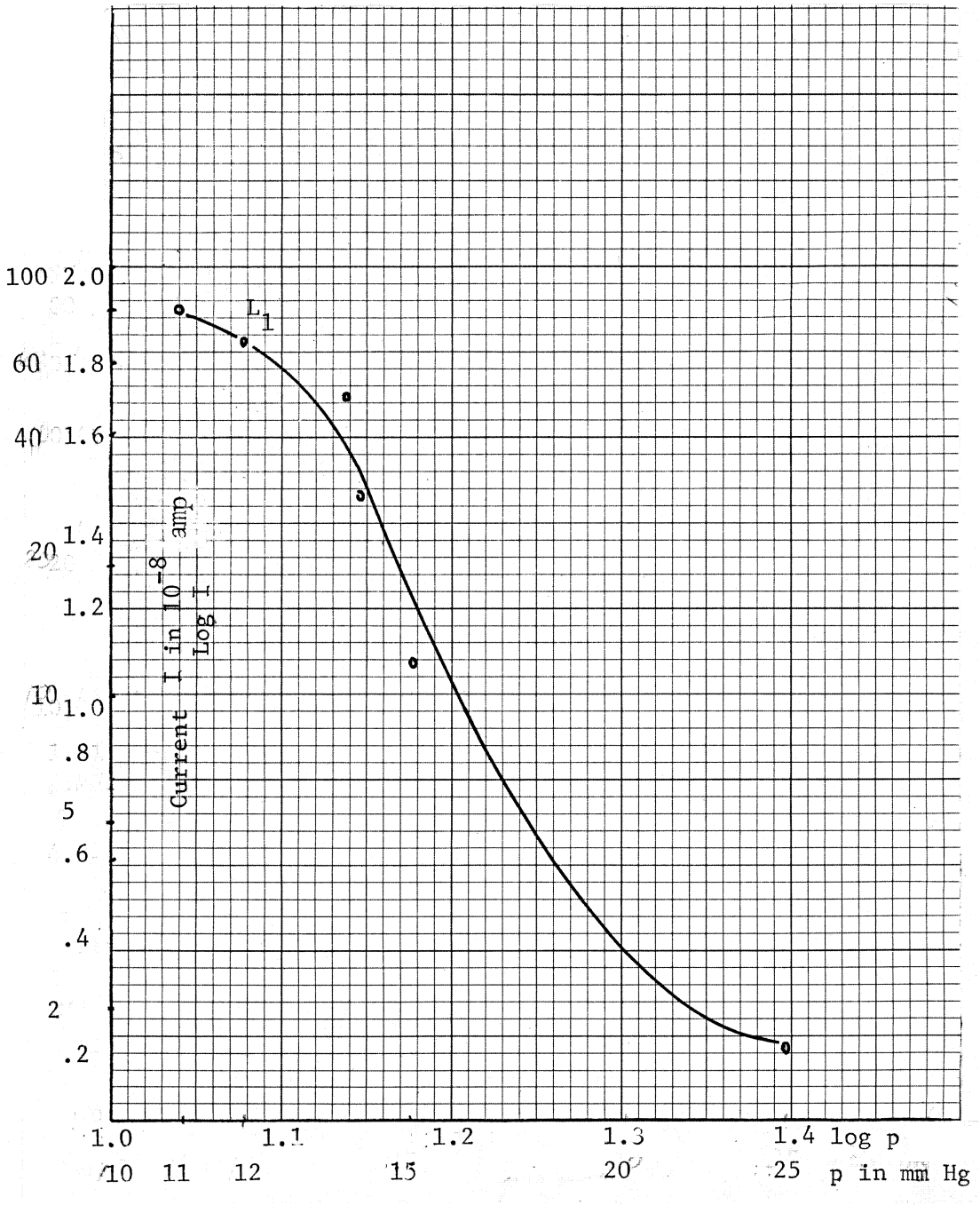


Fig.D.1.c i-p curve for V = 610V.
d = 0.42 cm with source #2
in air S^{i}_{pmax} = 10.8

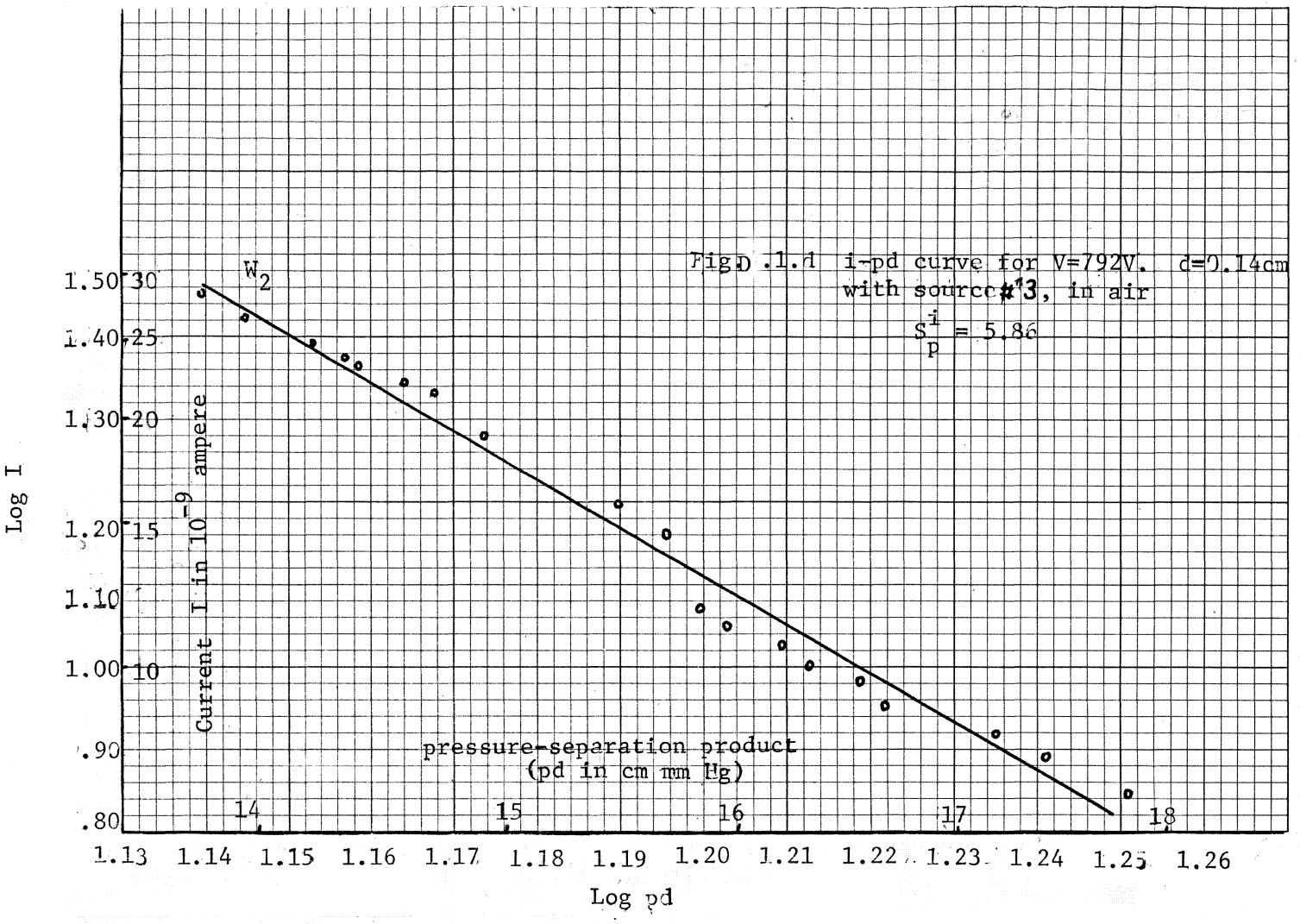


Fig D .1.d i-pd curve for V=792V. d=0.14cm
with source #13, in air
$S_p^i = 5.86$
W_2
Log I
Current I in 10^{-9} ampere
1.50 30
1.40 25
1.30 20
1.20 15
1.10
1.00 10
.90
.80
pressure-separation product
(pd in cm mm Hg)
14
15
16
17
18
1.13 1.14 1.15 1.16 1.17 1.18 1.19 1.20 1.21 1.22 1.23 1.24 1.25 1.26
Log pd

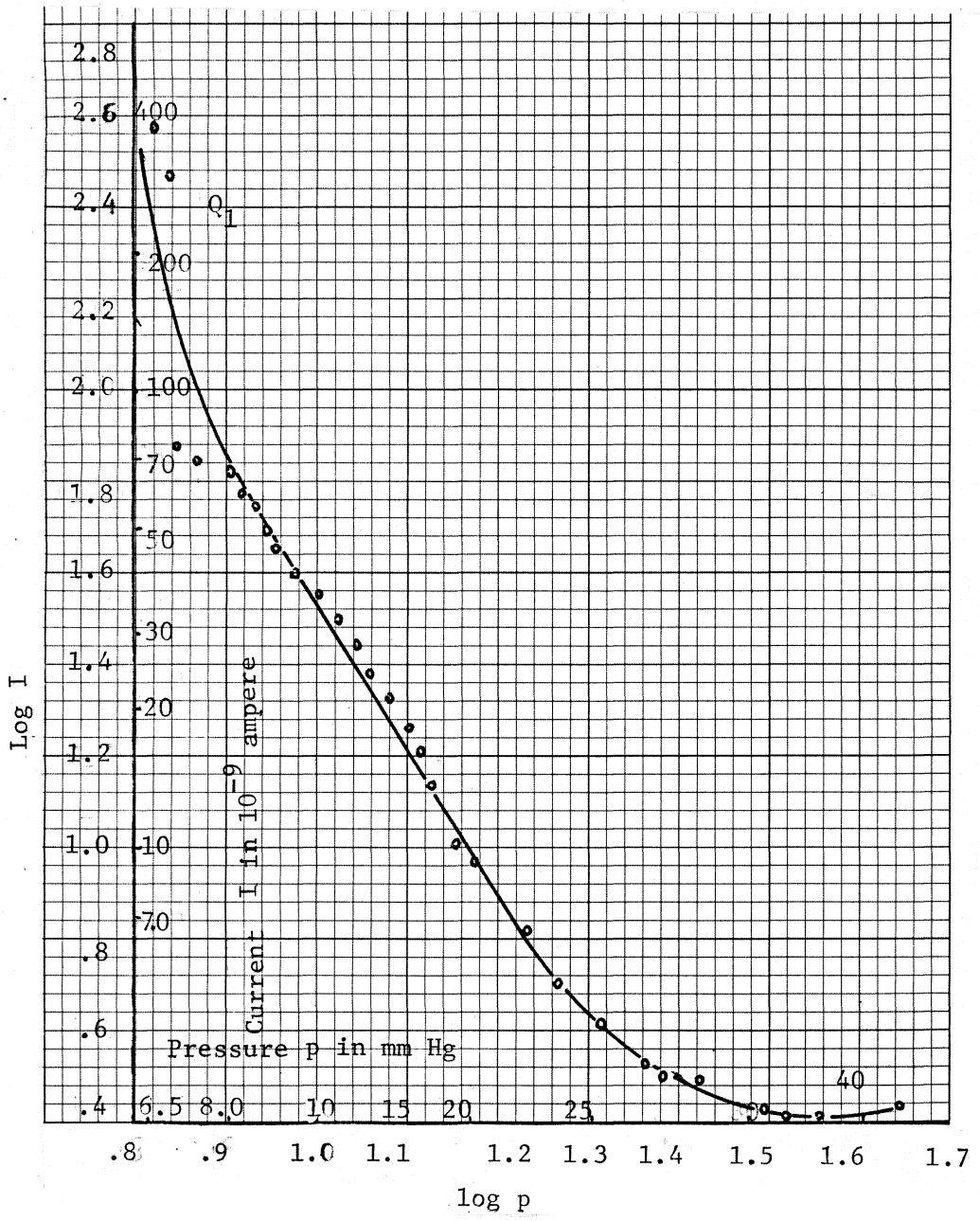


Fig.D.1e i-p curve for V=610V. d=0.42 cm
with source #3 in air

$S_p^i = 3.05$

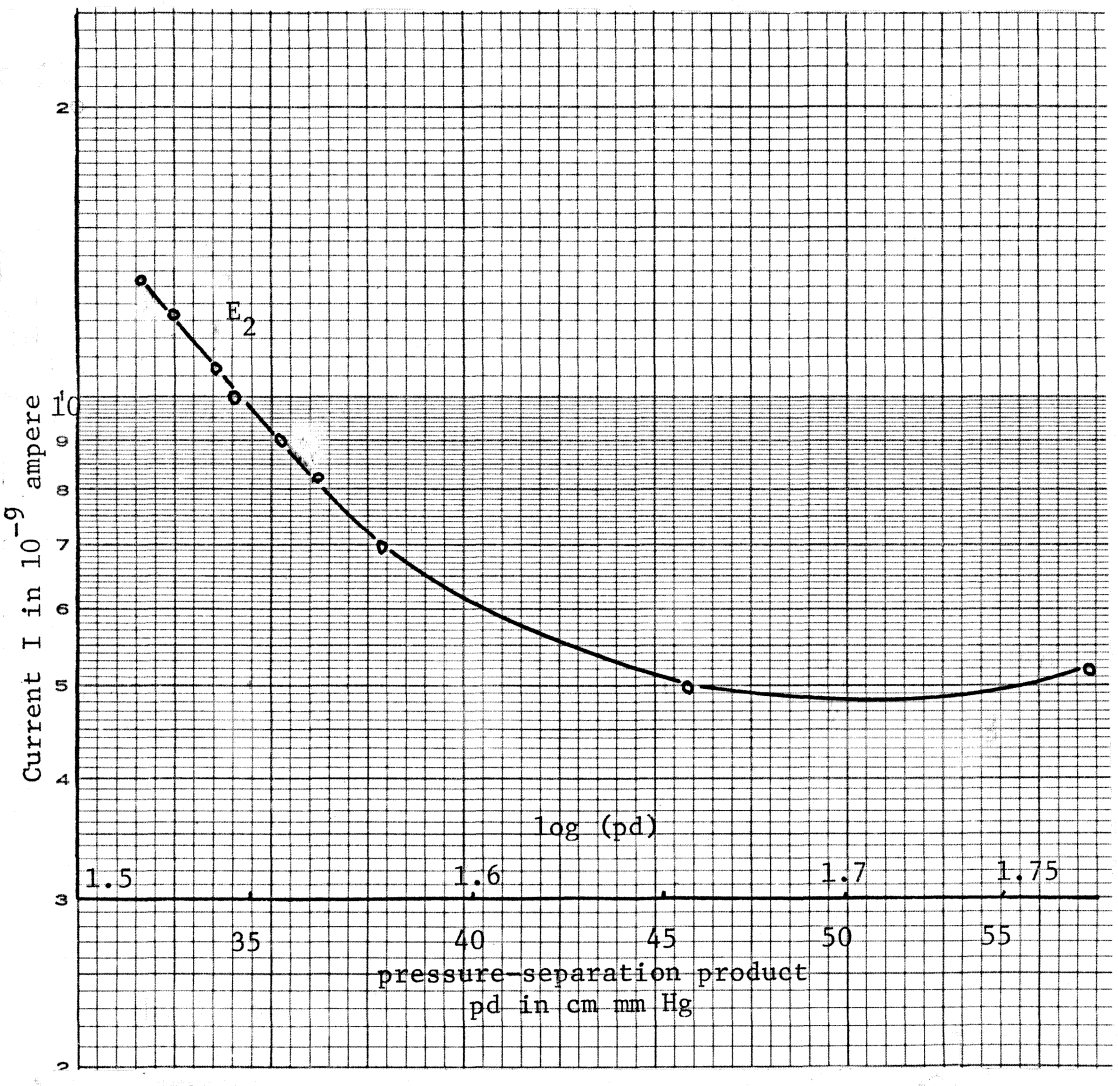


Fig.D.2a i-pd curve for V=1164V. d=0.082 cm
with source #3 in air

$S^i_{pmax} = 4.8$

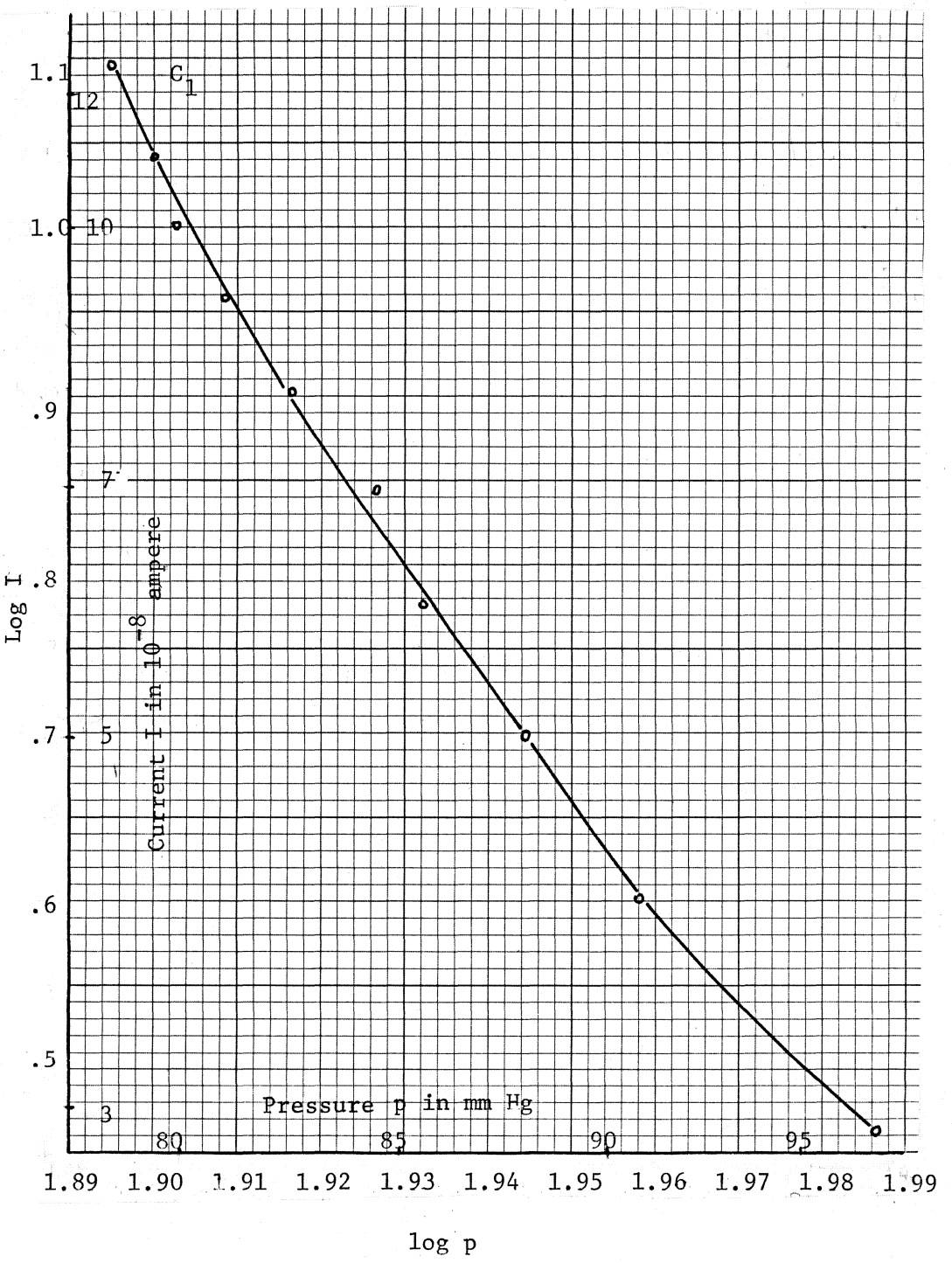


Fig.D.2.b i-p curve for V=1256V. d=0.21 cm
with source #2 in air $S_p^i = 10.1$

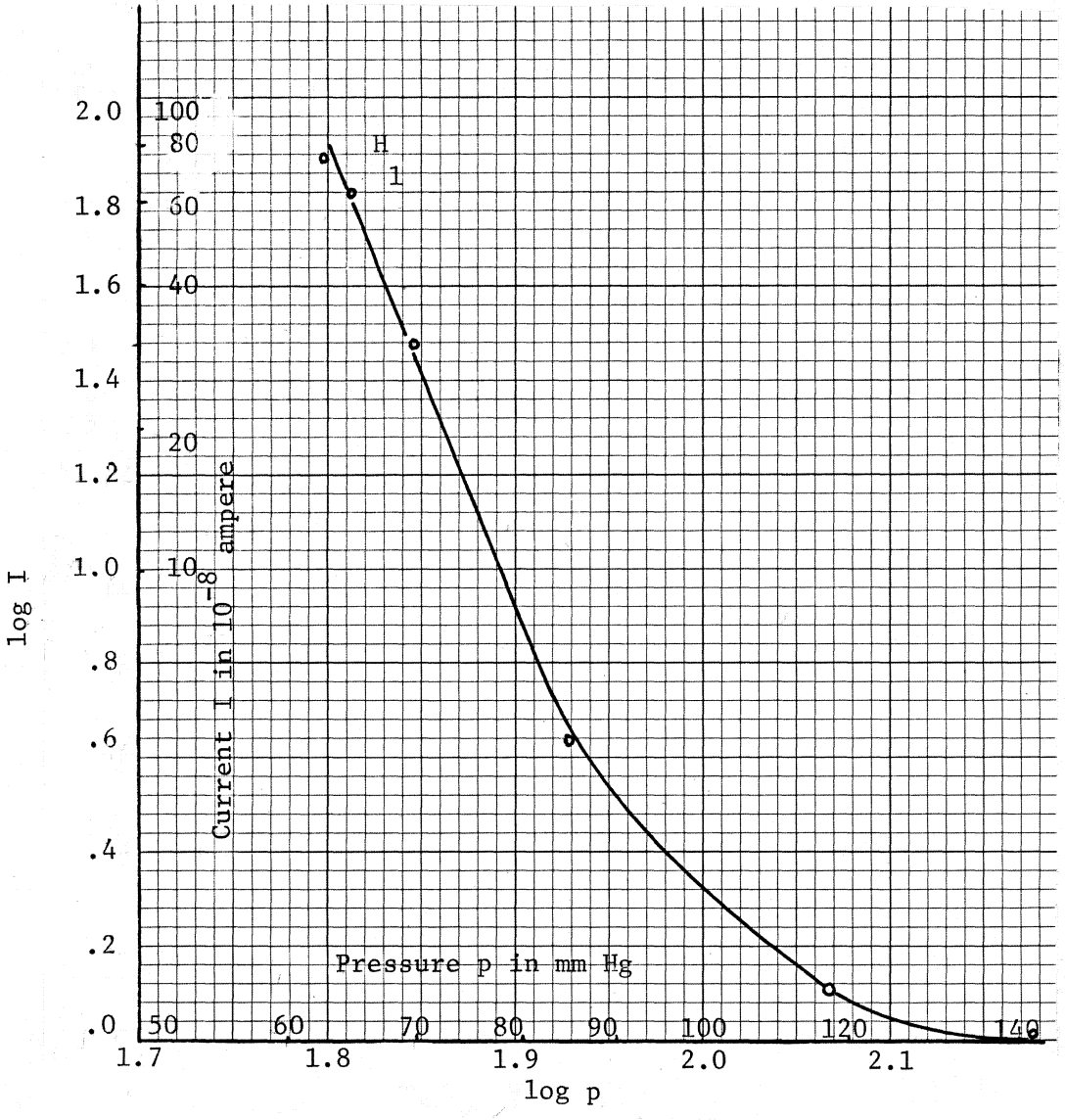


Fig.D.2.c i-p curve for V=1256V. d=0.21 cm
with source #2 in air $S^{i}_{pmax} = 9.5$

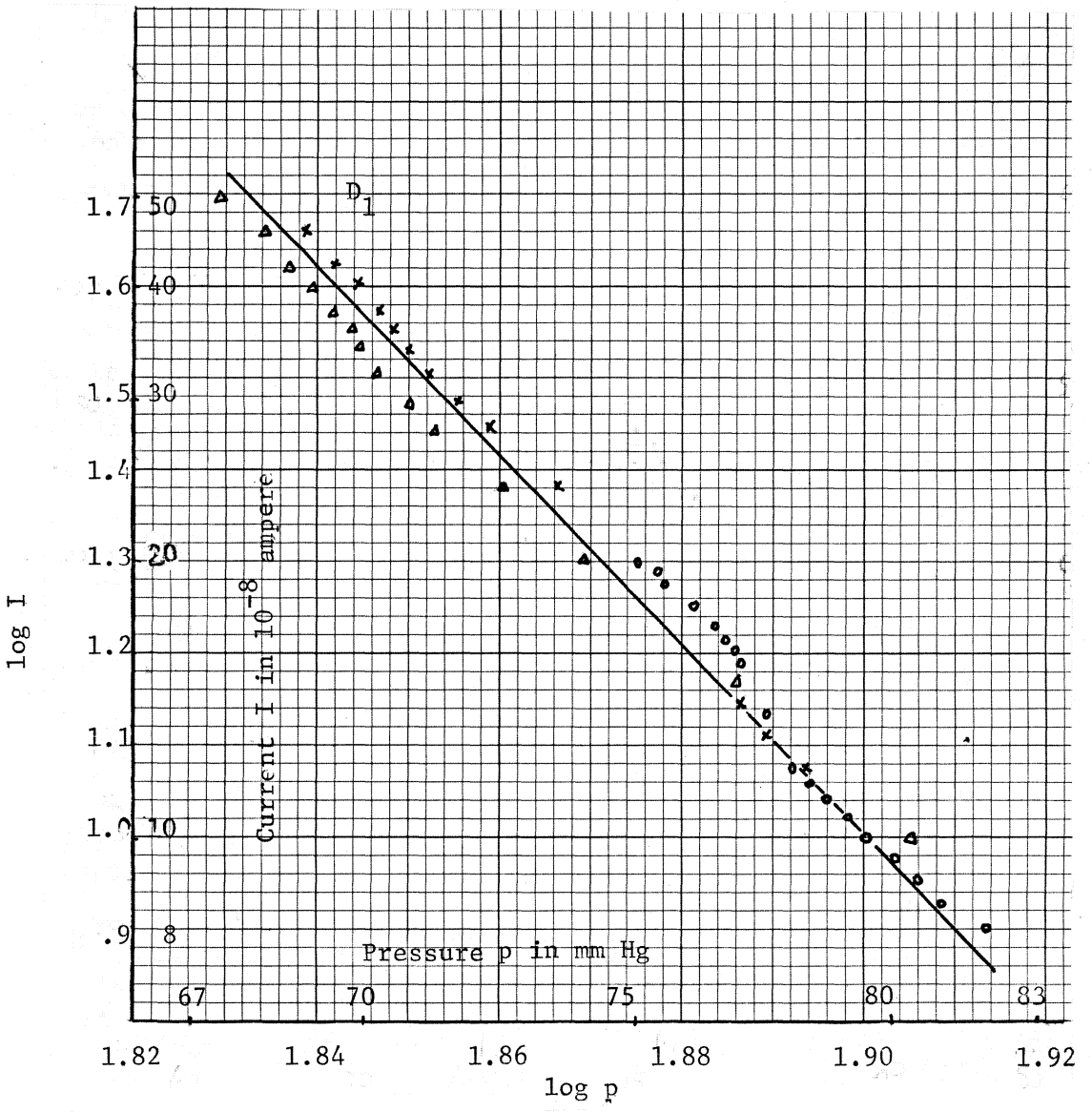


Fig.D.2d i-p curves for V=1256V. d=0.21 cm
with source #2 in air $S_p^i = 9.3$

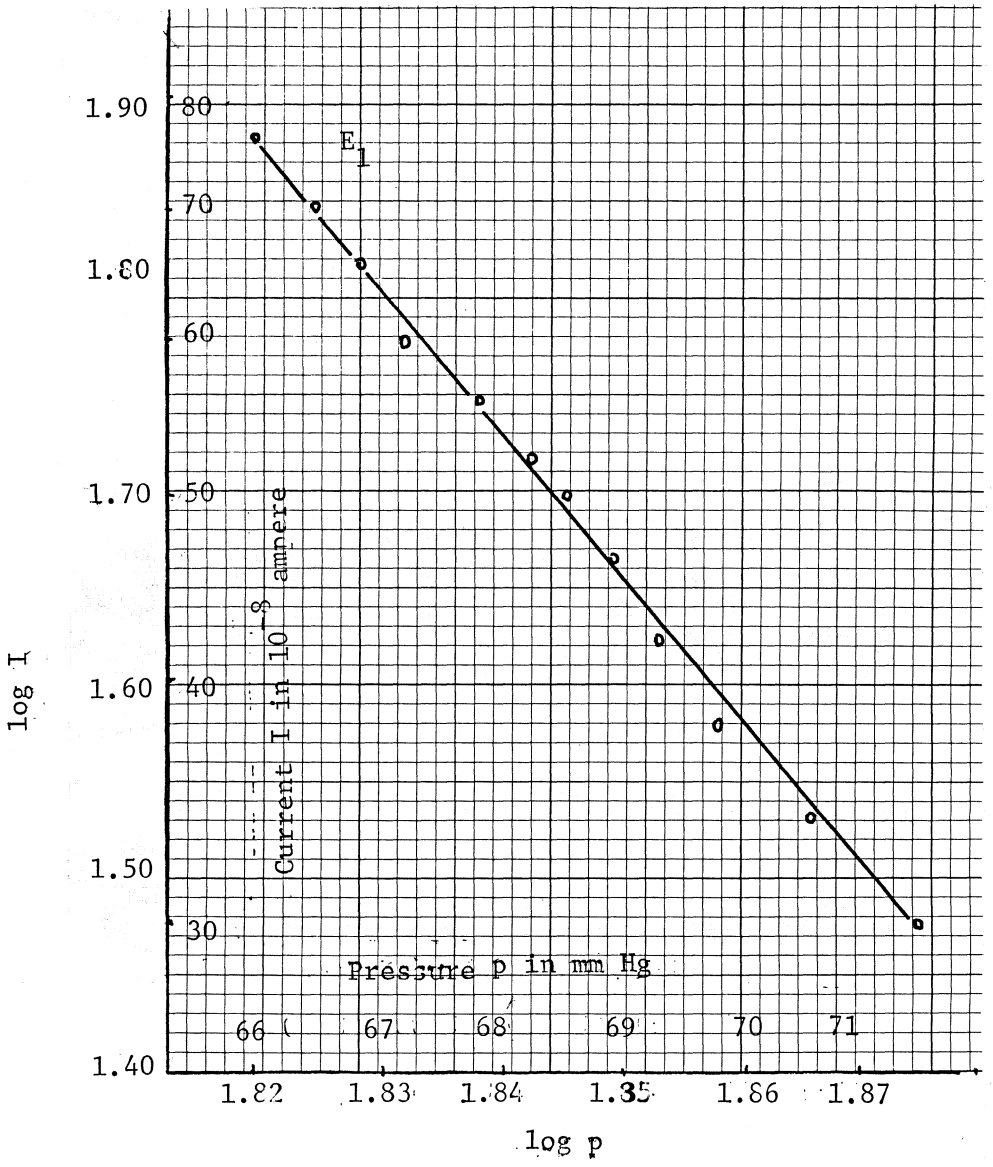


Fig. D.2.e i-p curve for V=1256V.
d=0.21 cm with source #2
in air $S_p^i = 11.7$

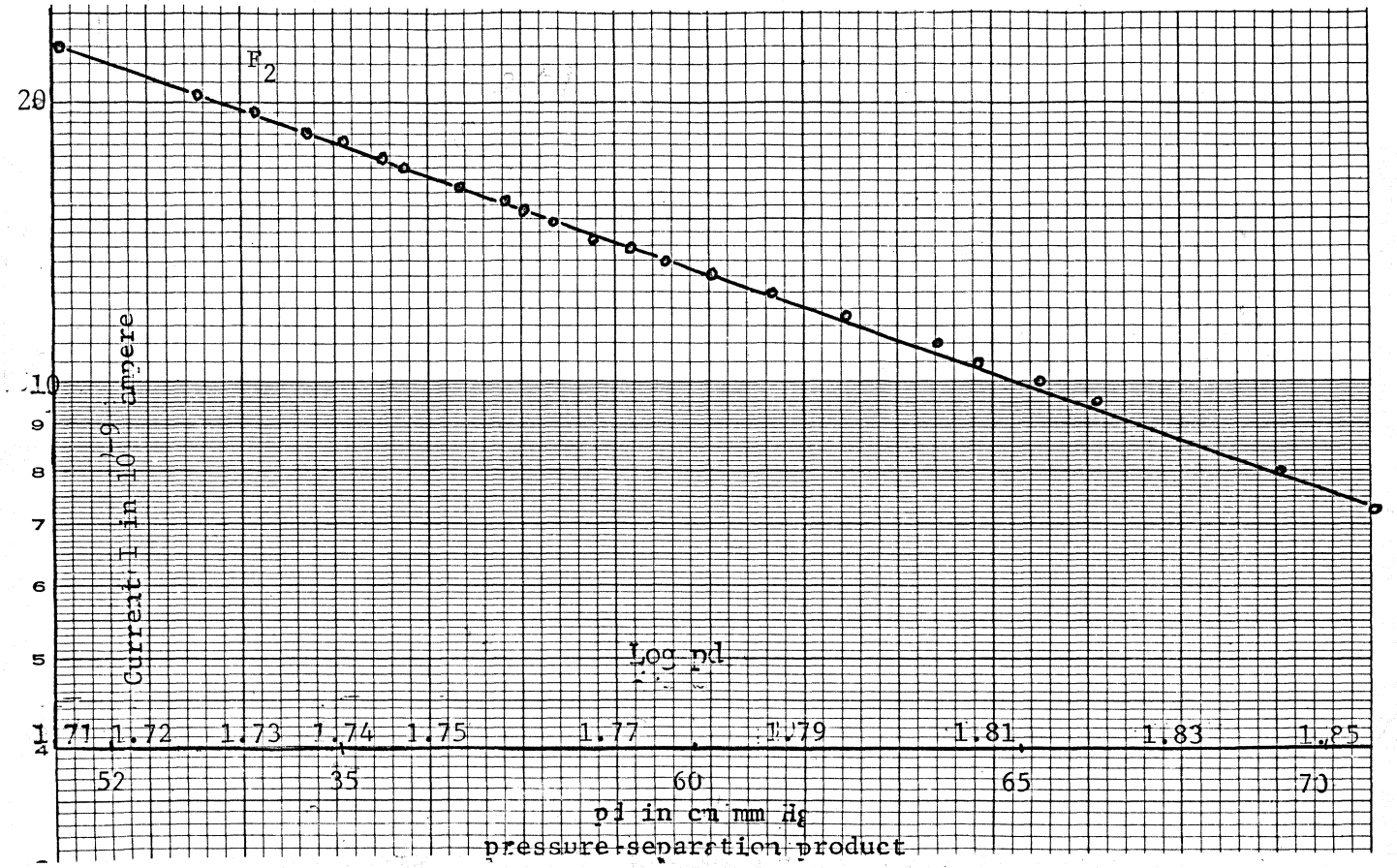


Fig.D.2.f i-pd curve for V=1256V. d=0.114 cm with source #3 in air

$S_p^i = 2.59$

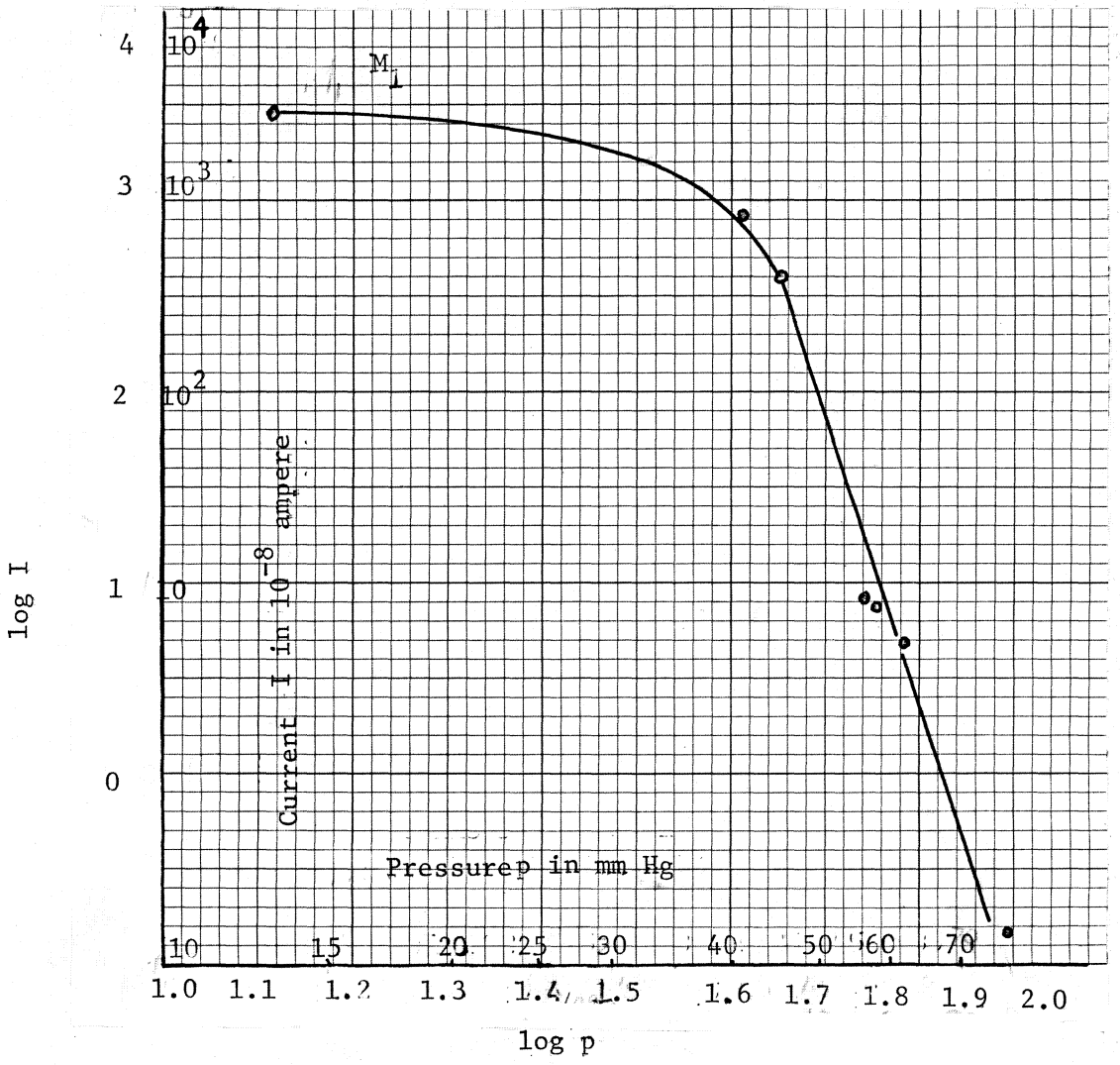


Fig.D.2.g i-p curve for V=1256V. d=0.42 cm with source #2 in air S = 14.9

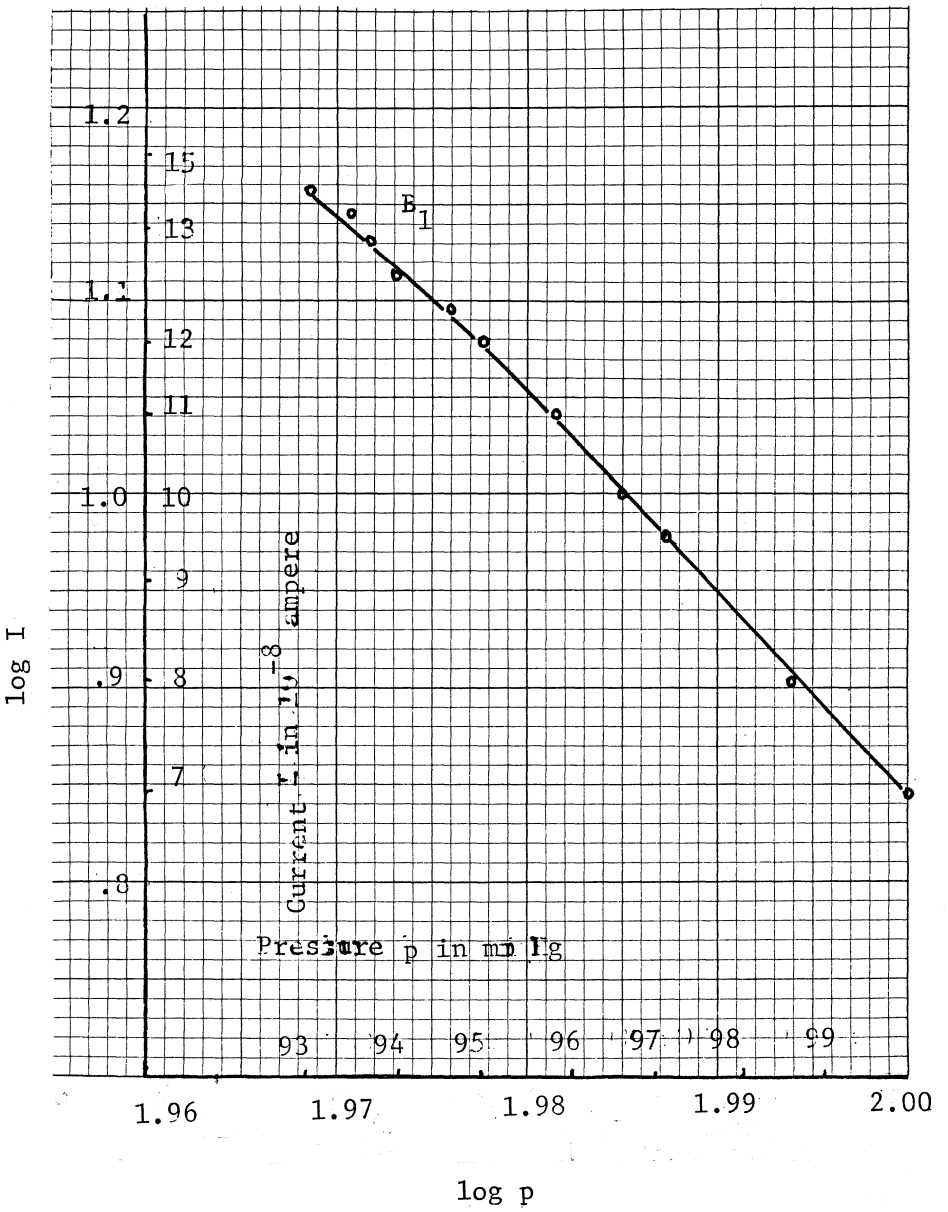


Fig D .2.h i-p curve for V=1440V.
d=0.21 cm with source #2
in air $S_p^i = 10.5$

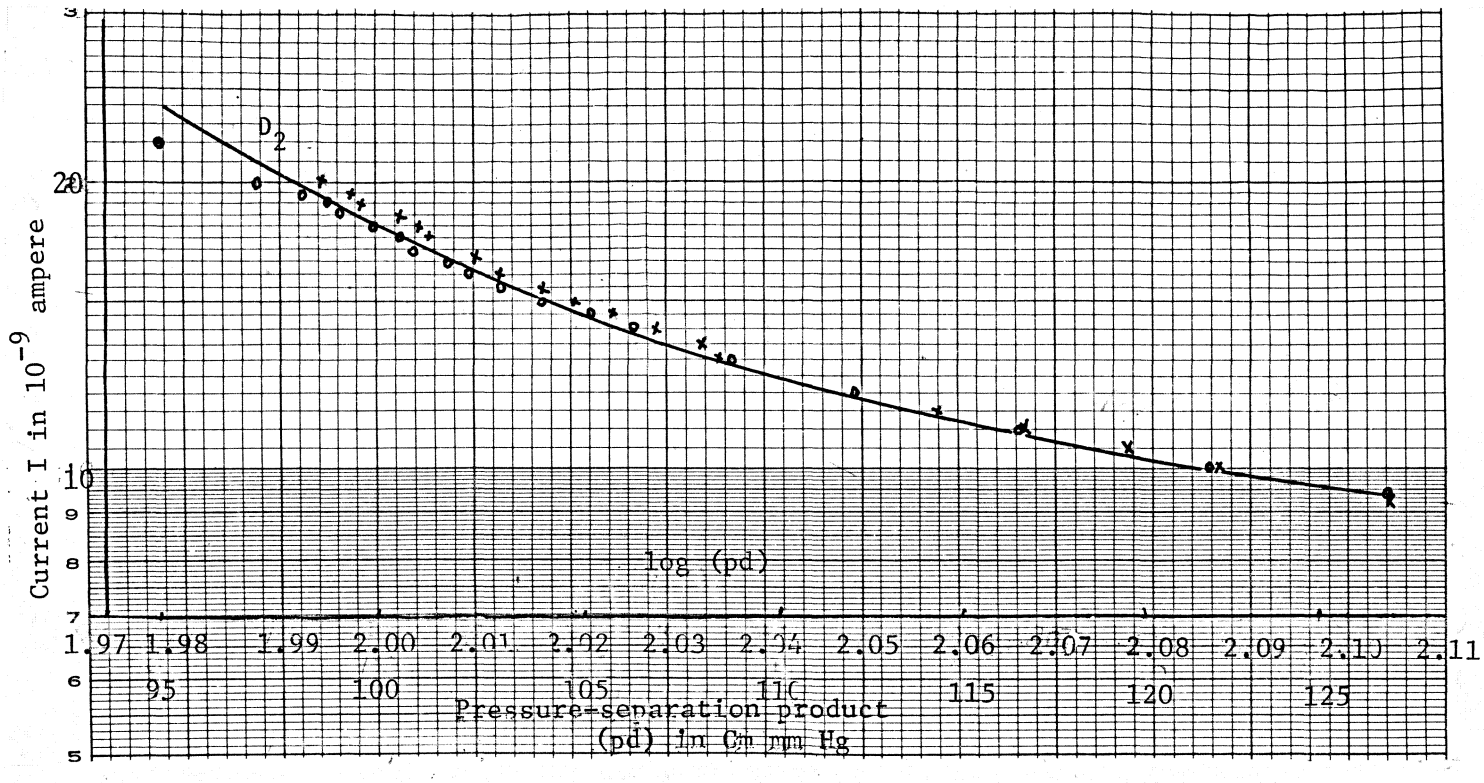


Fig. D.2.i $i-pd$ curve for V=1550V. d=0.18 cm with source #3 in air
S_p^i = 1.57 - 5.36

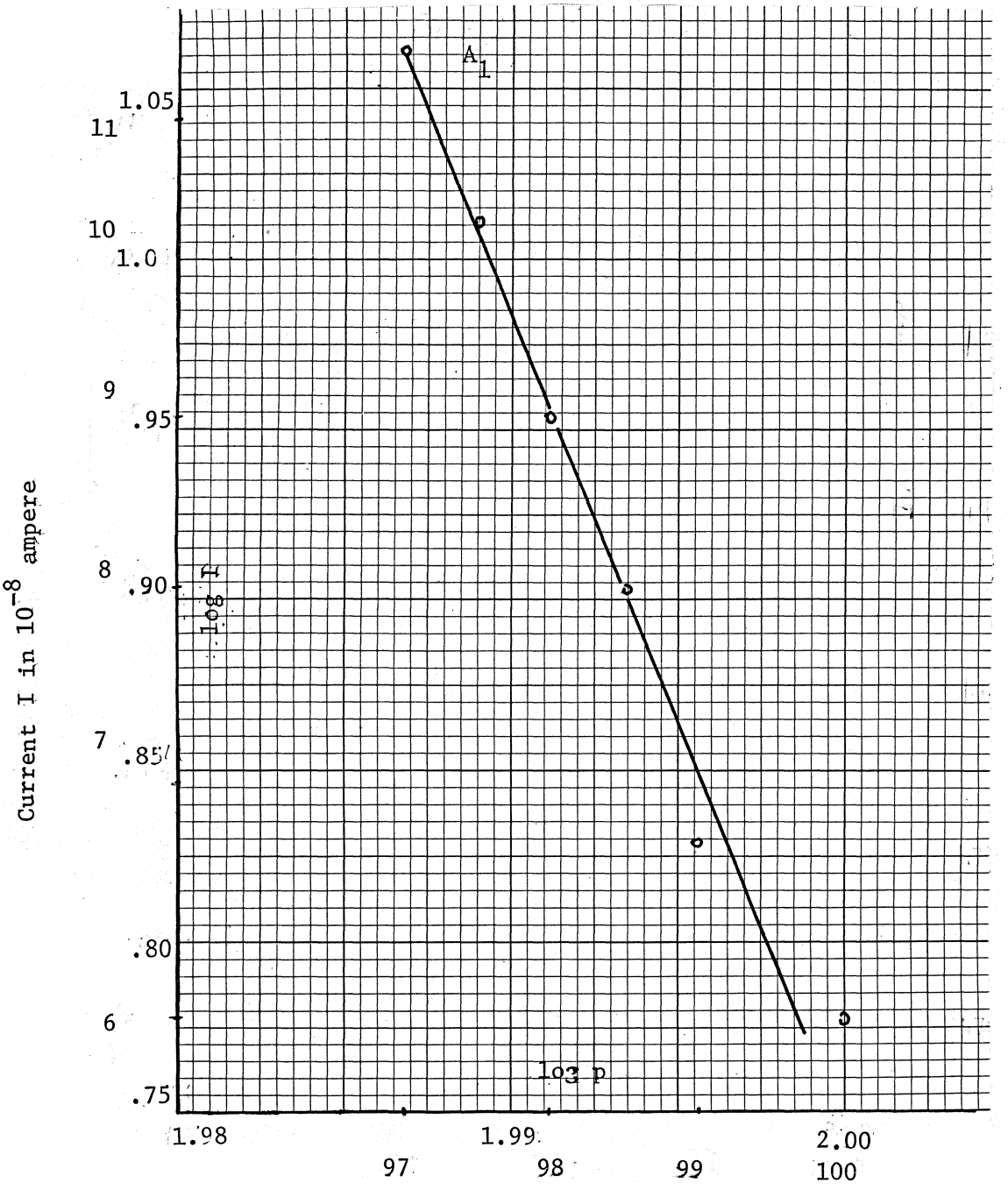


Fig.D.2.j i-p curve for V=1640V. d=0.21 cm
with source #2 in air $S_p^i = 24$

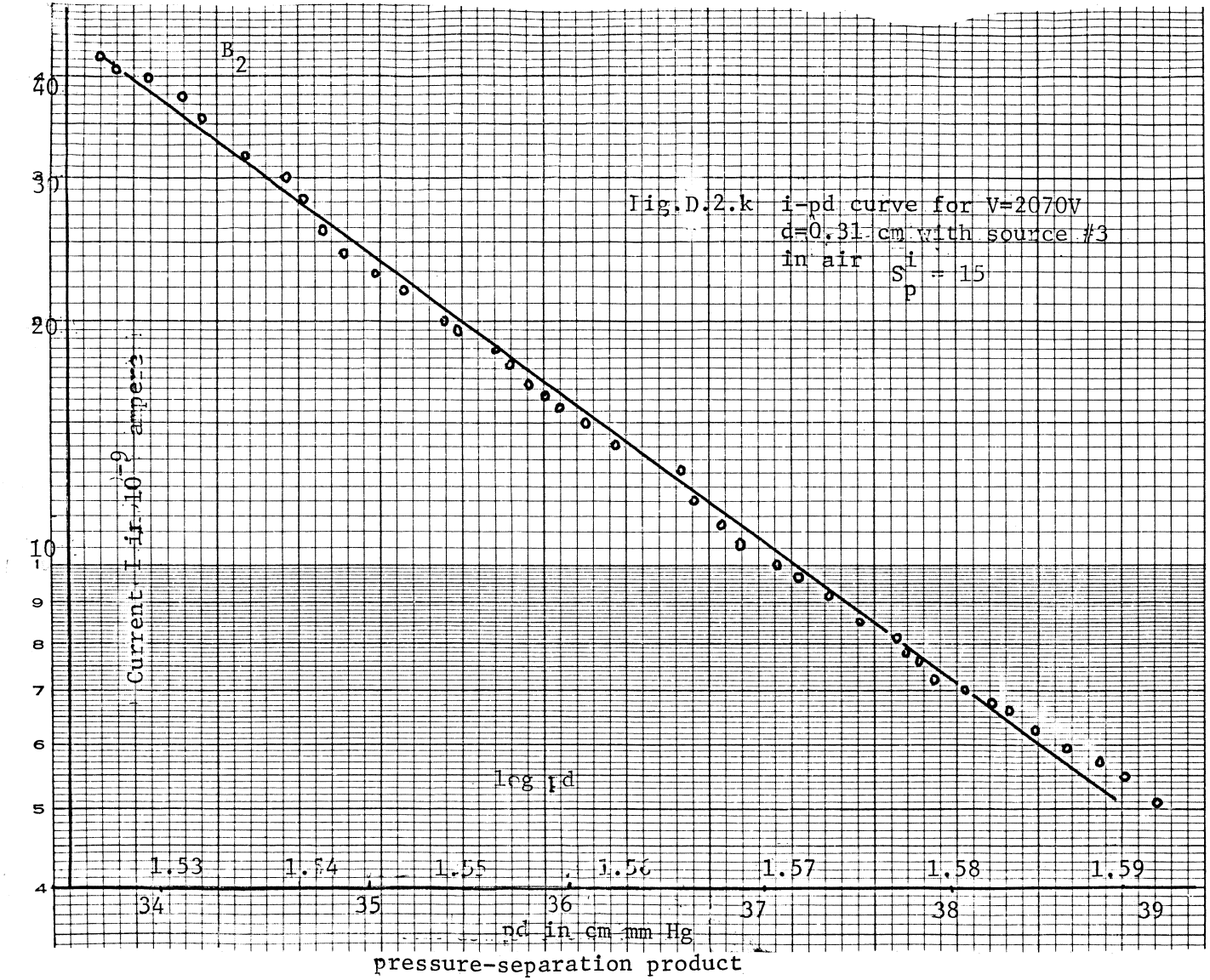


Fig.D.2.k i-pd curve for V=2070V
d=0.31 cm with source #3
in air $S_p^i = 15$

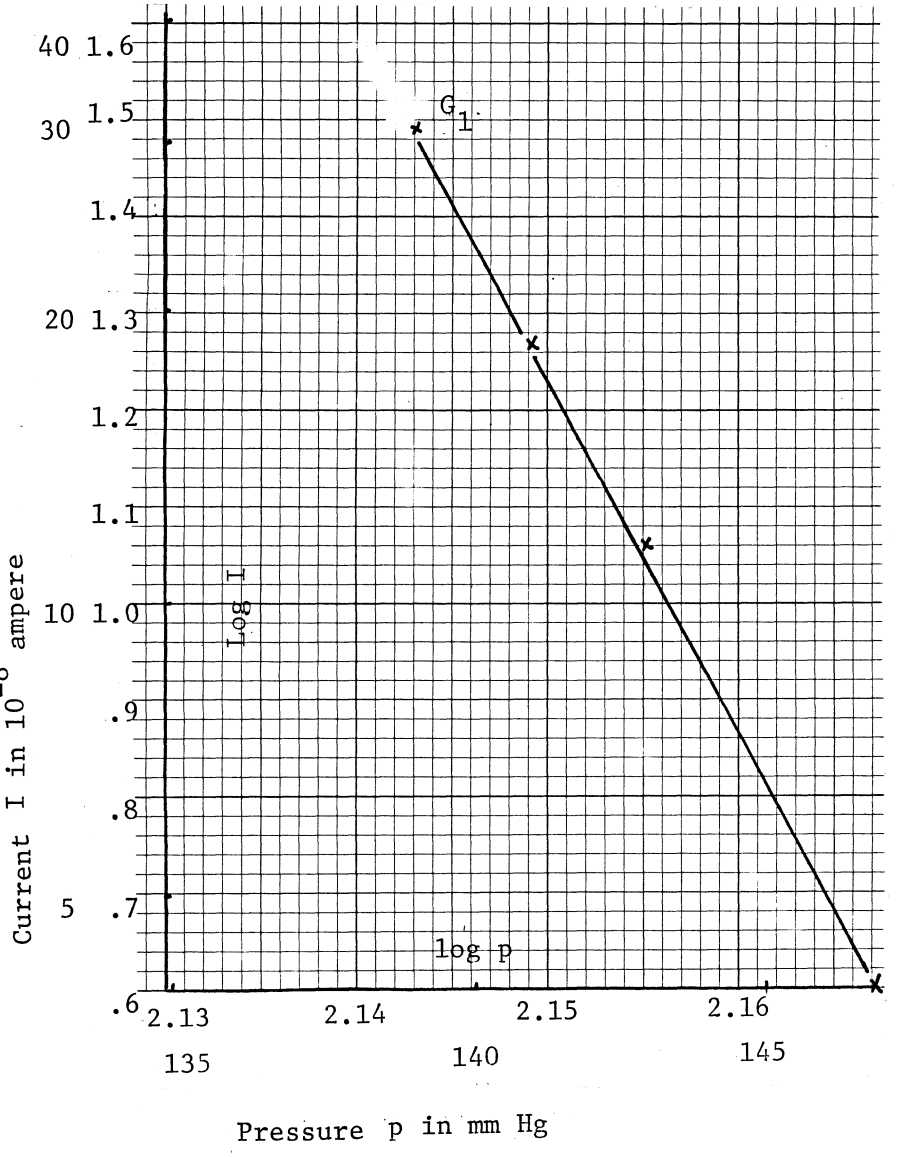


Fig.D.2.1 i-p curve for V.=2120V.
d=0.21 cm with source #2
in air S_p^i = 36.4

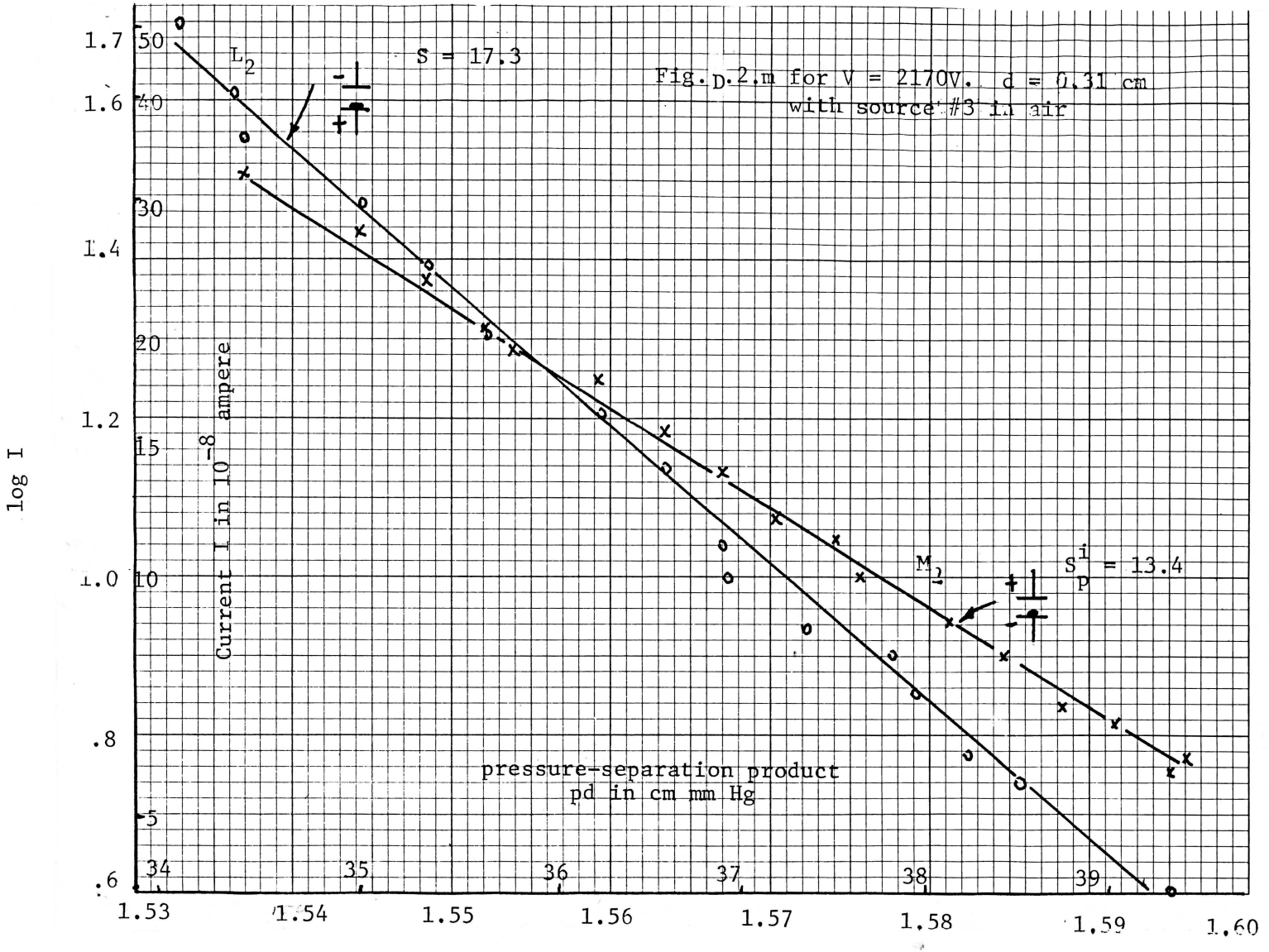


Fig. D.2.m for V = 2170V. d = 0.31 cm
with source #3 in air
S = 17.3
L_2
M_2
S_p^i = 13.4
Current I in 10^{-8} ampere
log I
pressure-separation product
pd in cm mm Hg
log pd
1.7
1.6
1.4
1.2
1.0
.8
.6
50
40
30
20
15
10
5
34
35
36
37
38
39
1.53
1.54
1.55
1.56
1.57
1.58
1.59
1.60

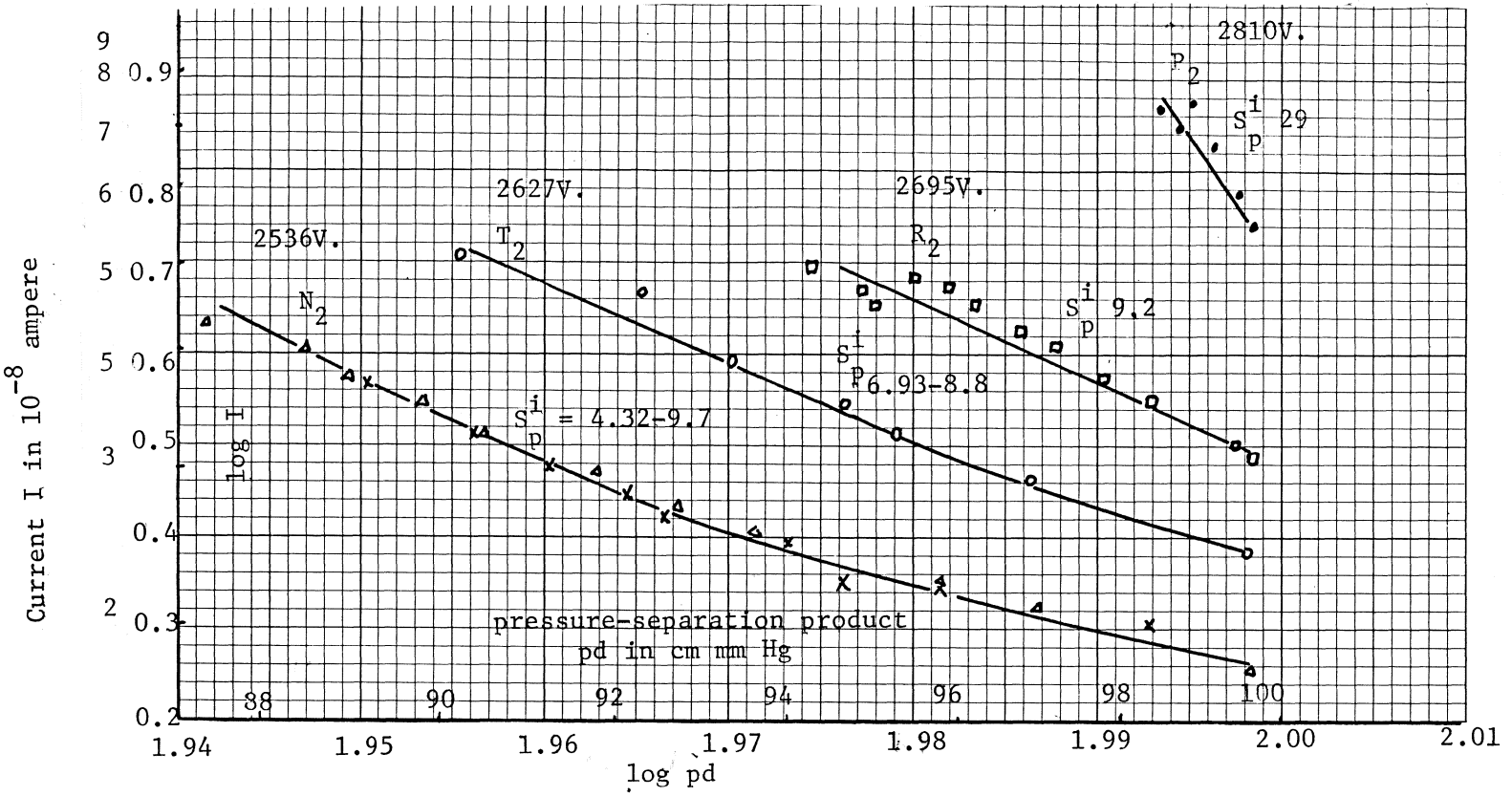


Fig. D.2.n i-pd curves for d=0.14 cm with source #3 in air

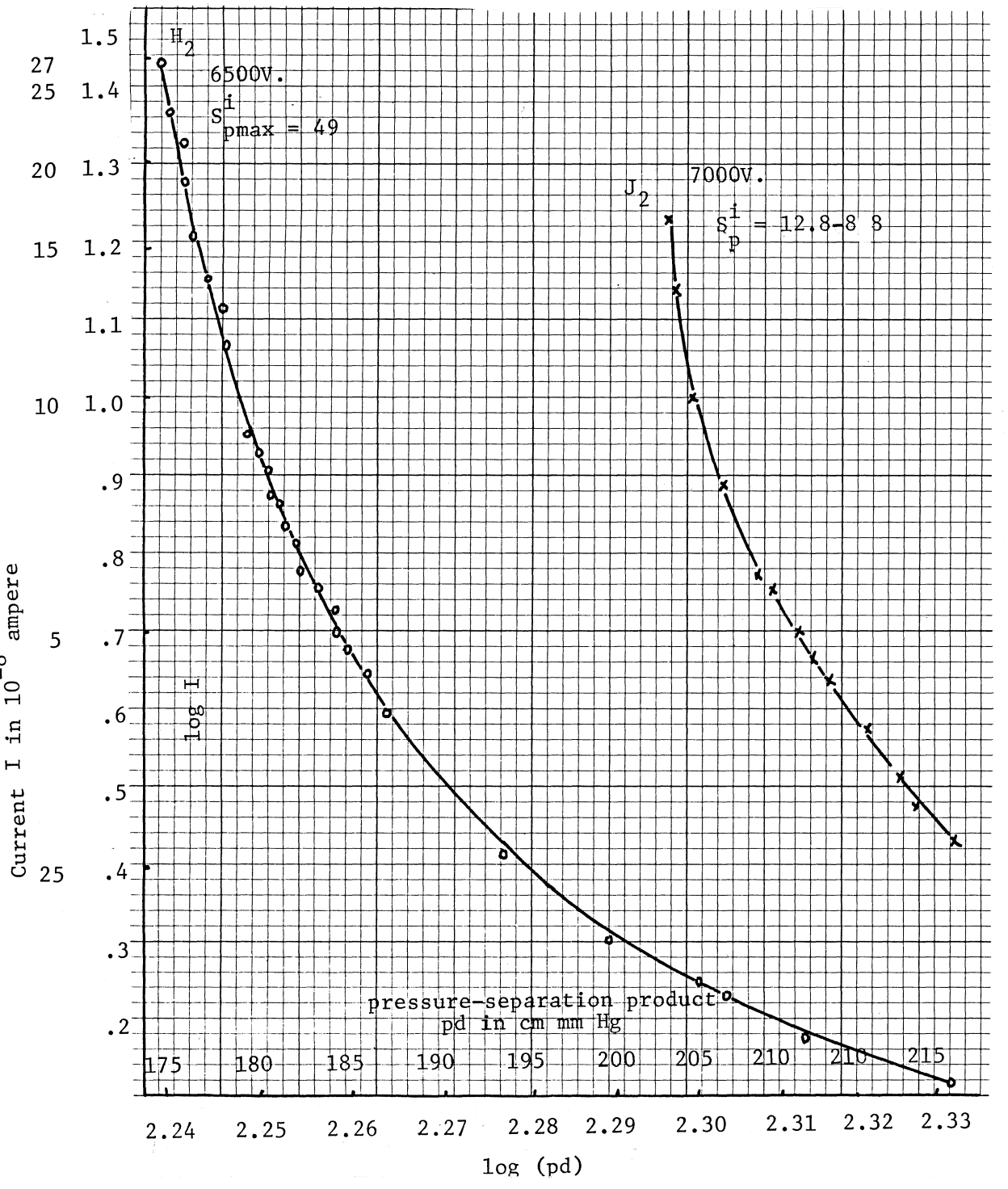


Fig. D.2.q i-pd curves for d = 0.31 cm with source #3 in air

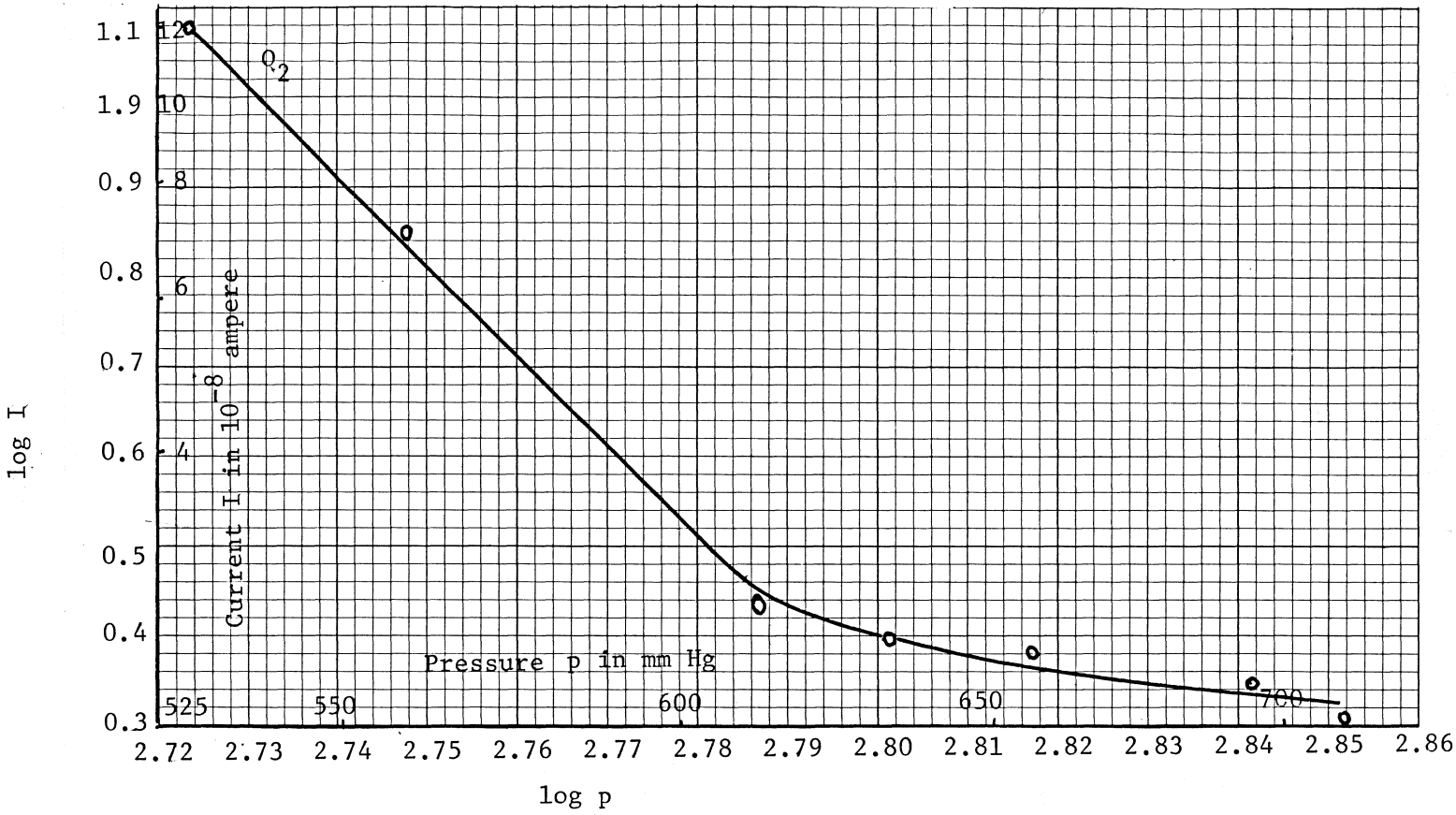


Fig.D.2.r i-p curve for V=11.5KV d=0.80 cm with source #3 in air

$S_p^i = 10.2$

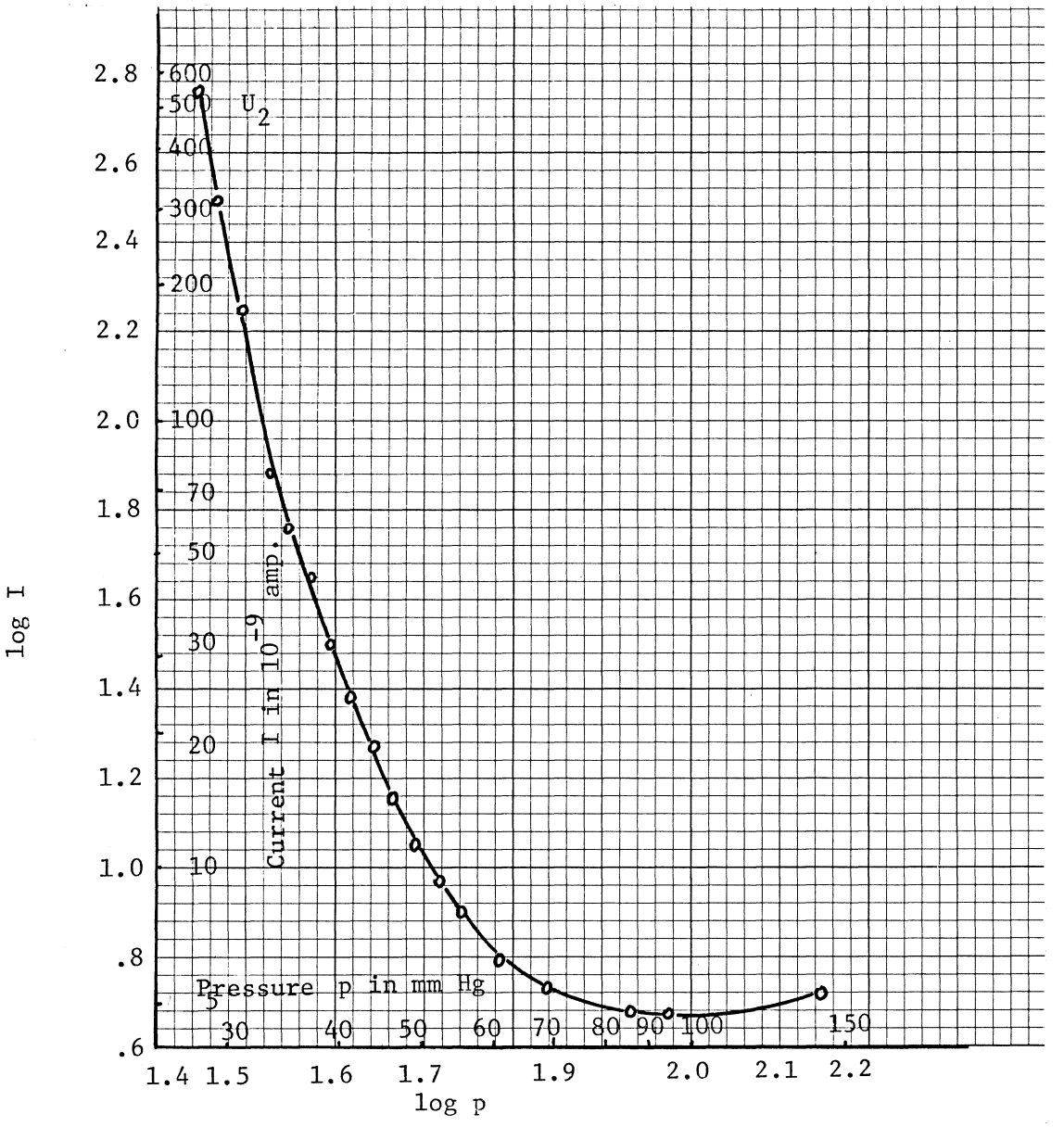


Fig. D.2.s i-p curve for V=1256V. d=0.42 cm with source #3 in air $S\frac{i}{p}_{max}$ = 10.6

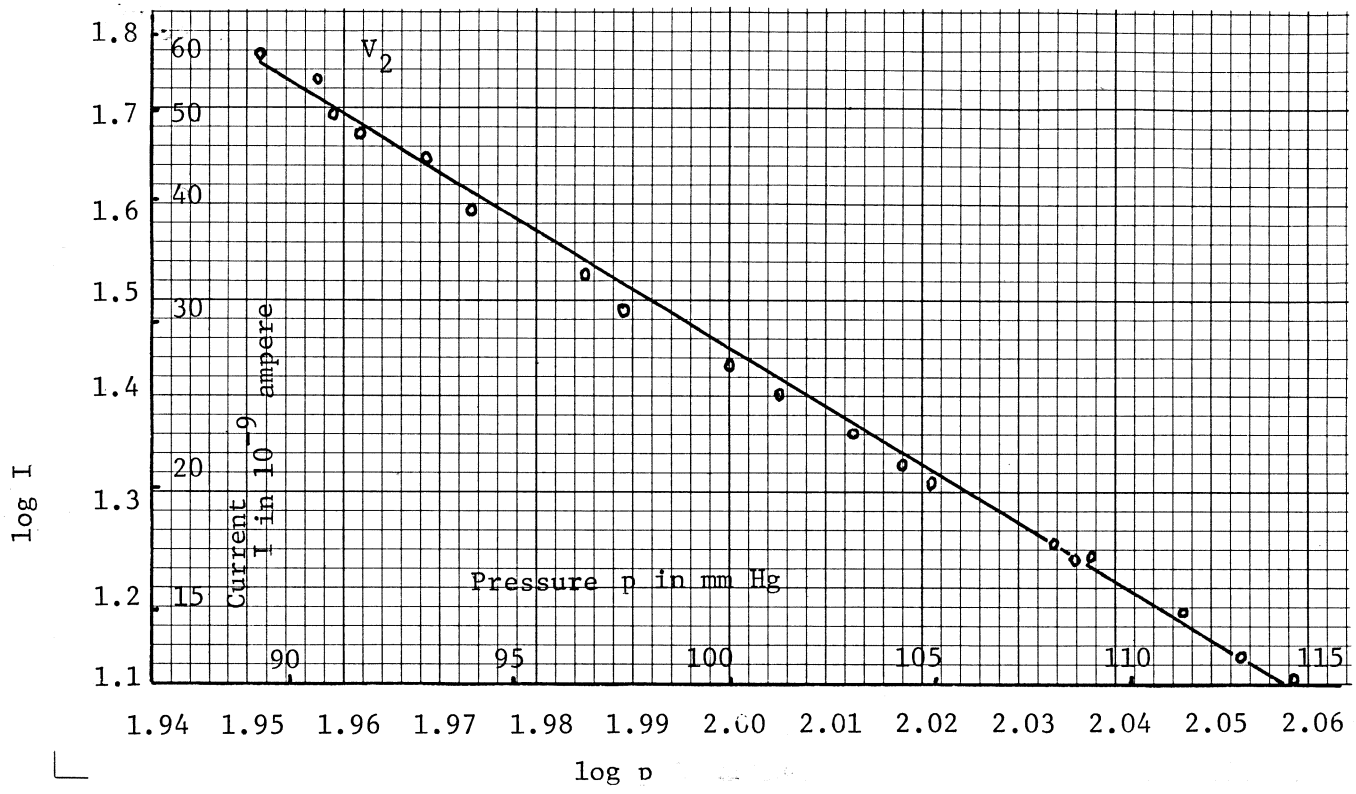


Fig. D2.t for V=1256V. d=0.21 cm with source #3 in air

$S_p^i = 6$

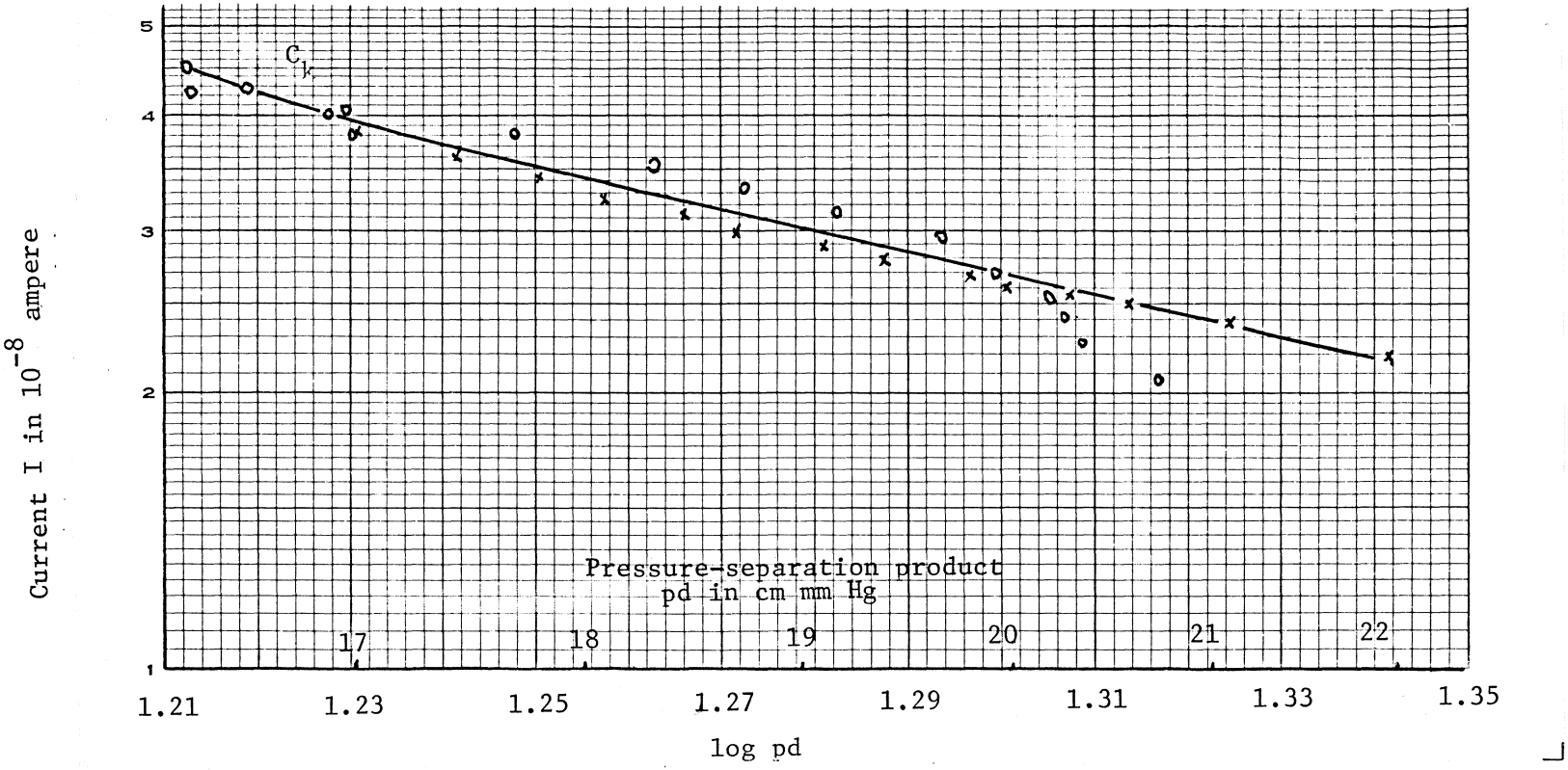


Fig.D.3.a i-pd curve for V=410V. d=0.14 cm with source #3 in Krypton

S_p^i = 2.12 - 3.39

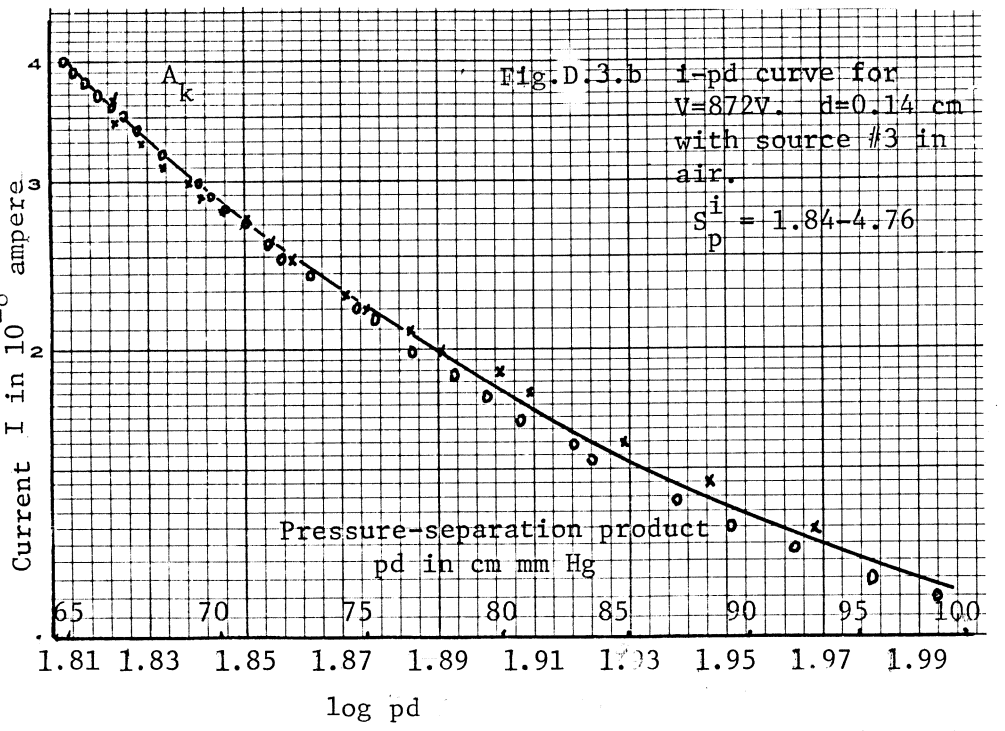


Fig. D.3.b i-pd curve for V=872V. d=0.14 cm with source #3 in air.
S_p^i = 1.84-4.76

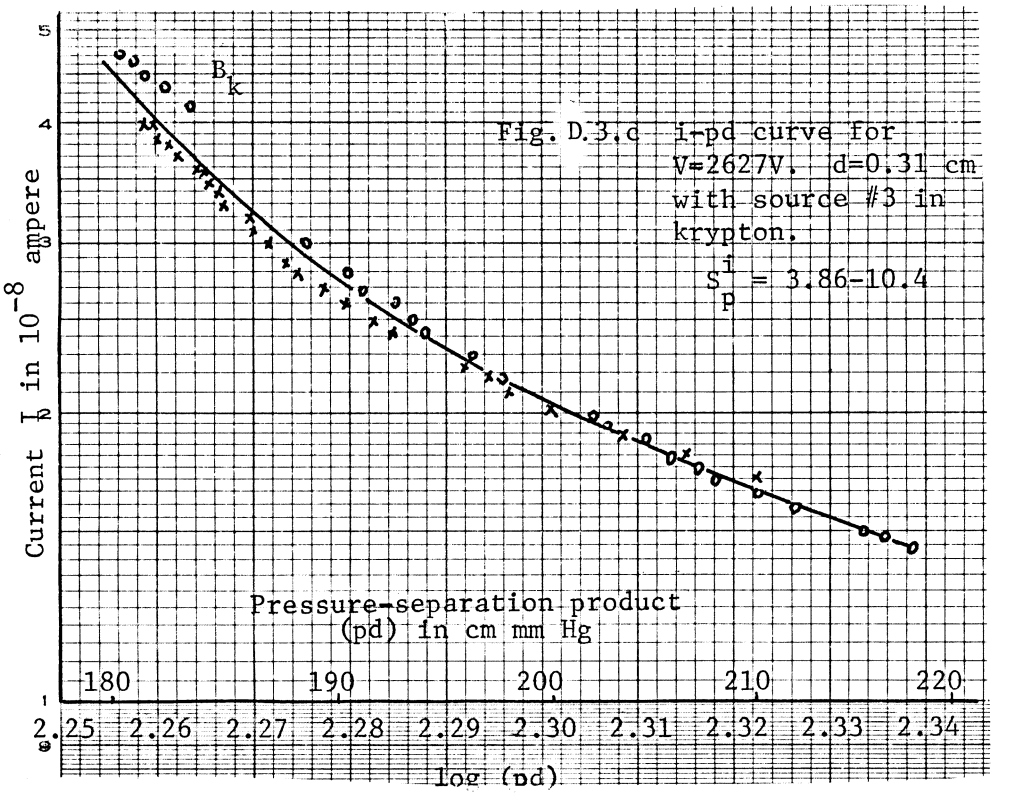


Fig. D.3.c i-pd curve for V=2627V. d=0.31 cm with source #3 in krypton.
S_p^i = 3.86-10.4

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INVESTIGATION OF THE FEASIBILITY OF SENSING TRANSIENT VELOCITY BY MEANS OF GASEOUS IONIZATION

by

Hsien-Lu Huang

ABSTRACT

Sensitivity S_p^i is defined as the ratio of the fractional change of gas ionization current to the fractional change of gas pressure. A maximum obtainable sensitivity was calculated, $S_p^i\Big]_{max} = -0.309\frac{A}{B}$ V, where A, B are constants for a given gas within a particular range of field-to-pressure ratio. Experiments were conducted to investigate the sensitivity of air and krypton under different combinations of voltage, electrode separation and primary electron source strength. A curie of tritium placed on the central portion of either electrode produced a constant initial emission current and a high sensitivity. Sensitivity could be increased by using a stronger current source, higher voltage and a larger electrode separation. Observed values of S_p^i for high voltage at larger separation are greater than those expected even when breakdown occurs at a (pd) quite larger than the one for $S_p^i\Big]_{max}$. The fractional pressure change, $\frac{\Delta p}{p}$, is independent of the initial pressure, p, and is greater for a heavier gas subject to the same acceleration, a fact which suggests the use of a heavier gas to obtain a higher fractional current change for the same

sensitivity. Krypton behaves in a similar way as air in the system. Operating current level may be higher than 10^{-5} ampere if stronger source is used. There is a limit in the separation for a given source configuration. Further increase in S_p^i and current level may be achieved through better design of the configuration and location of the current source between the electrodes. The fractional current change, $\frac{\Delta i}{i}$, depends more on Δp rather than on the initial operating pressure, p.

From the experiment performed, it appears that a gas system will perform satisfactorily as a transient velocity gauge.