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High Energy Electron Beam Excitation of a Gas

Don T. Froedge
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Don T. Froedge entitled "High Energy Electron Beam Excitation of a Gas." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Physics.

Arthur A. Mason, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

February 24, 1967

To the Graduate Council:

I am submitting herewith a thesis written by Don T. Froedge entitled "High Energy Electron Beam Excitation of a Gas." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Physics.

Arthur A. Mason
Major Professor

We have read this thesis and recommend its acceptance:

Sidney Soltzman

John B. Dicks Jr.

Accepted for the Council:

Hilton A. Smith
Vice President for
Graduate Studies and Research

HIGH ENERGY ELECTRON BEAM EXCITATION OF A GAS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Don T. Froedge

March 1967

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It gives me pleasure to acknowledge the help given me in the process of this study. My most sincere thanks to Mr. Roger Whetsel who worked closely with me on this study, and Mr. William Gannon for his invaluable technical skill. I also wish to express thanks to Mr. David S. Bynum of ARO, Inc., who directed this work, and to my advisor, Dr. A. A. Mason of the University of Tennessee Space Institute.

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CHAPTER I

INTRODUCTION

Since 1951 when Schopper and Schumacher (1)[1] first described a system for measuring gas densities with an electron beam, there has been continual interest in the application of this technique to aerodynamic studies. Despite its potential and rising popularity, there are many experimental problems and unanswered questions concerning the interaction of the beam with the gas and the radiation resulting from this interaction. The purpose of this investigation was to understand better the interaction of a particular electron beam-flowing gas system.

The first problem encountered in the study was developing the equipment necessary to conduct the experiment. The parameters involved have been ill defined or not defined at all, and a "cut and try" method was necessary. After several disappointing attempts, a system was developed which serves all the purposes intended and can be used for future investigations.

An electron beam may be used to excite to high energy levels the atoms and molecules of a mixture of gases. By

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[1]Numbers in parentheses refer to similarly numbered references in the bibliography.

spectroscopically examining the radiation emitted when these particles decay to lower energy levels it is possible to identify and determine the percentage of gases in the mixture.

This work is devoted to the determination of the percentage of helium in helium-air mixtures. In such measurements it is nearly impossible to get an absolute accounting of all the affecting factors. Most of the variables can be eliminated, however, by taking the ratio of intensities of a helium spectral line to an air spectral line. A correlation between this ratio and the percentage of helium in the gas mixture is postulated. This document summarizes a study which has been made of this intensity ratio over a wide range of density, temperature, beam energy, and mixture ratio. The results of these studies show that under the conditions of the experiment the technique is valid for determining the percentage of helium in the gas mixture.

CHAPTER II

EXPERIMENTAL SYSTEM

I. GENERAL DESCRIPTION

The system for this study consisted of a low pressure section, in which was encased an electron gun, and a high pressure section, containing the gas being excited (Figures 1 and 2). A small orifice separated the two sections and diffusion pumps maintained the low pressure in the gun section. Monochrometers were used to observe the emitted radiation. A copper tank encased the high pressure section to cool it with liquid nitrogen.

II. ELECTRON GUN

The electron gun used to excite the gas is the same as is used in commercial television picture tubes. It provides beam currents up to 1000 microamps at 10 to 20 KEV which is sufficient to excite enough molecules to produce an observable light intensity. The high voltage is used to reduce spreading of the beam due to elastic collisions of the electrons with the gas molecules. The guns are relatively inexpensive and easily replaced. They will operate for long lengths of time in pressures on the order of 10^{-6} mm Hg, but can operate as high as 3×10^{-4} mm Hg. When

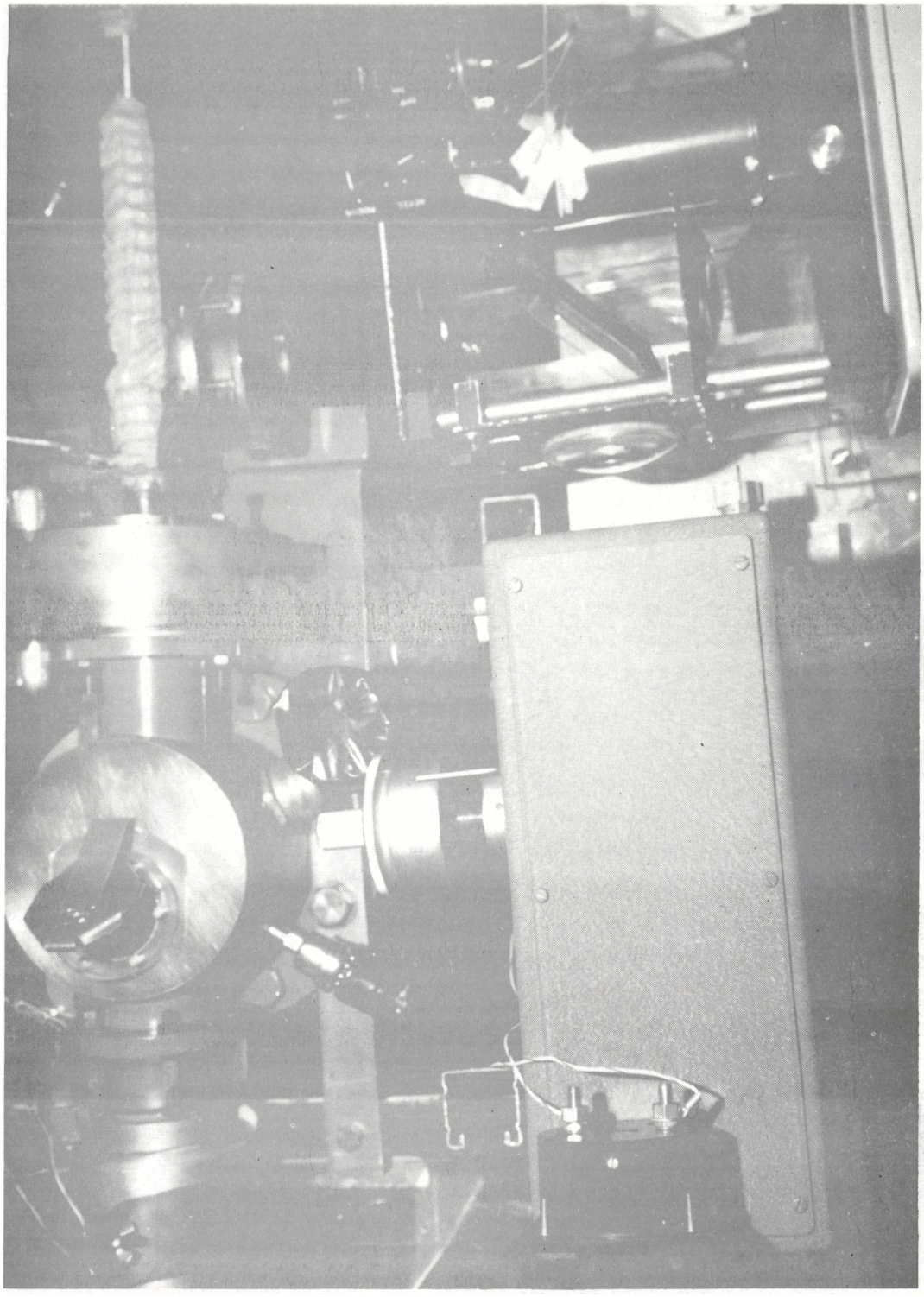

Figure 1. Photograph of entire system.

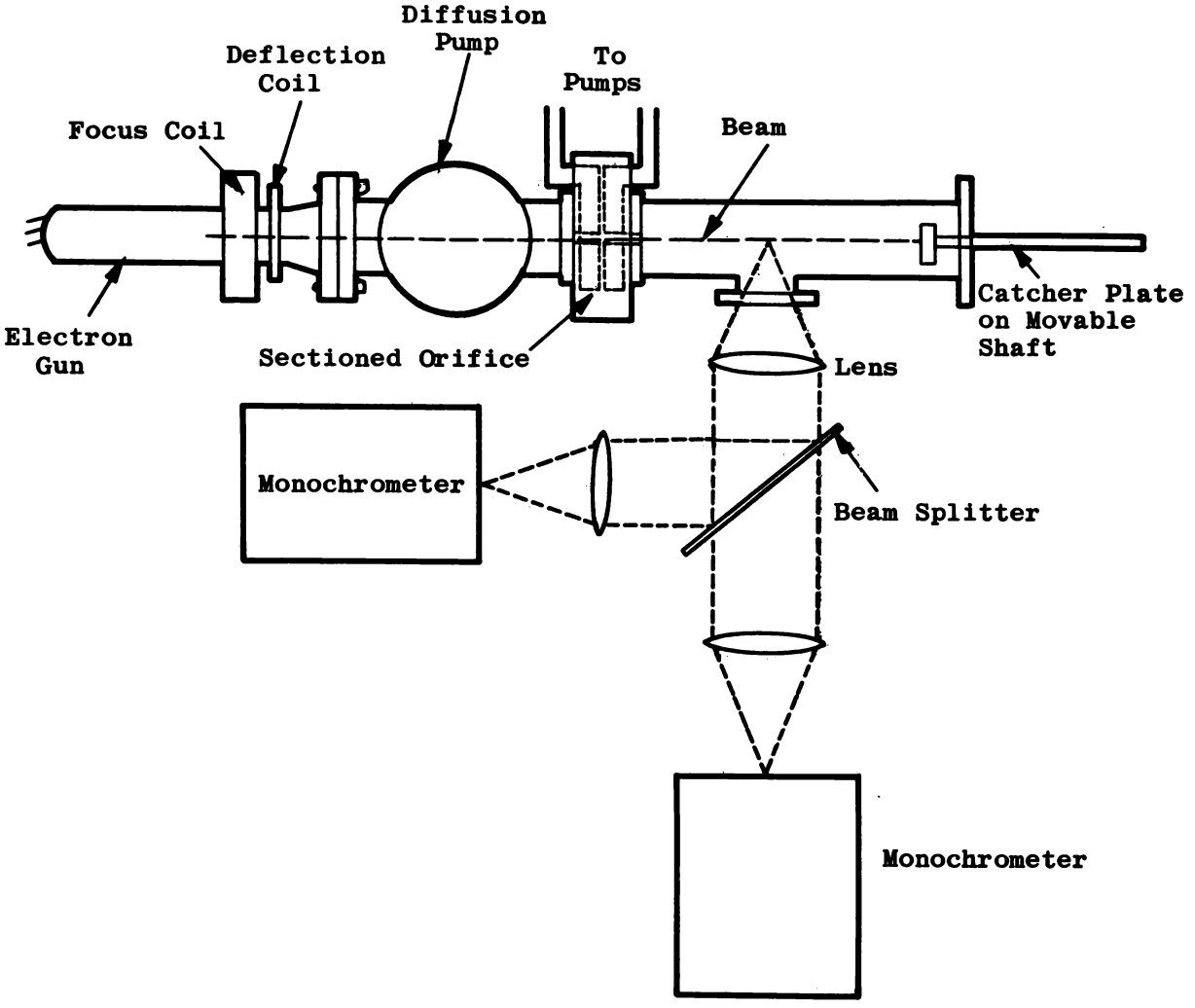

Figure 2. Electron beam experimentation system.

higher pressures are used, however, only short operating times are possible due to contamination of the coated cathode, which retards electron emission.

Since the gun chamber pressure is determined mainly by the pressure in the test section (see Figure 3), the life of the gun is determined by the pressure of the gas under study in the test section. There is a marked degradation of the performance of the gun each time it is brought up to atmospheric pressure. It is usually advisable to maintain the gun at low pressure if the time between data runs is on the order of one day.

Rated heater voltage on these guns is usually 6.3 volts, but they will withstand prolonged voltages of twelve to eighteen volts. Power for the heater and the magnetic deflection coils is provided by batteries for reasons of stability as well as for isolation from ground. Initial alignment of the beam is done through the window provided in the pump head.

III. THE VACUUM SYSTEM

The technique which allows a high energy electron beam to pass from a region of relatively low pressure in the electron gun chamber (10^{-6} mm Hg) to a region of relatively high pressure in the test section (3 to 5 mm Hg) is a dynamic differential pumping system. In this system the beam passes

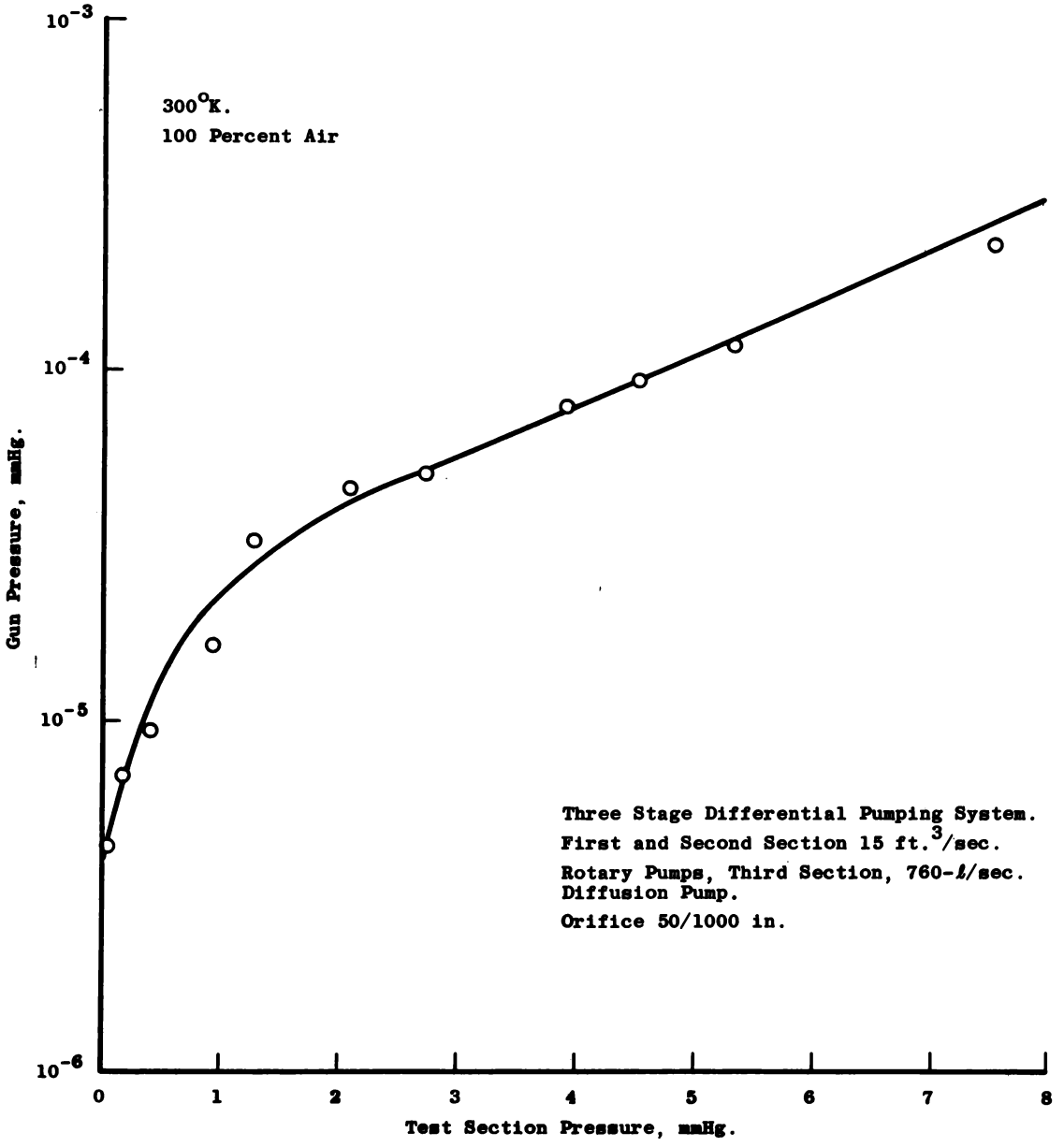

Figure 3. Pump characteristic curve (electron gun chamber pressure versus test section pressure).

through a series of three sections which are separate but connected by small orifices (one-twentieth of an inch in diameter). Each of these sections is connected to a 15 cubic-foot-per-minute capacity rotary vacuum pump, which removes the gas coming from the high pressure test section. The pressure is successively lowered in the three sections. The last section, which contains the gun, has a four-inch oil diffusion pump with a 760-liters-per-second capacity in front of the rotary pump (see Figure 4). Since the gas is being continually pumped out by the pumping system, a flow into the test section is necessary. This is provided by a high-pressure bottle connected to the test section through a variable leak. When mixtures of gases are used, the high-pressure bottles are filled with the mixtures needed in the chamber. This technique eliminates problems associated with mixing the gases by valve systems.

IV. ELECTRON BEAM CONTROLLER

Since a differential-pumping system is used, the electron beam must be directed through small orifices approximately 0.050 inches in diameter. In order to do this, a magnetic focusing coil is used to focus the electron beam down to a small spot. The beam direction is then controlled with a small set of magnetic deflection coils which are capable of driving it either horizontally or vertically.

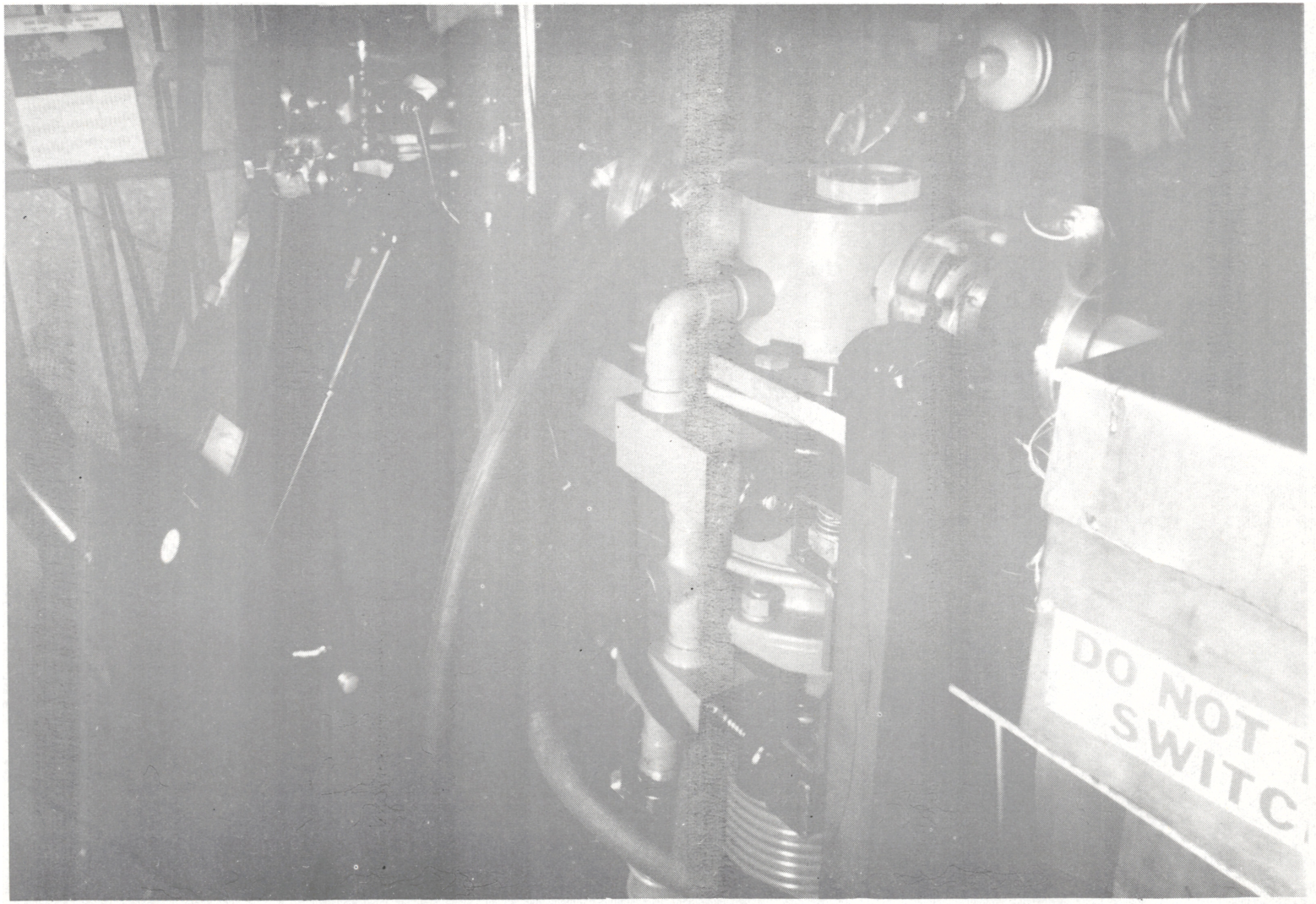

Figure 4. Photograph of differential pumping system.

In practice, it is very difficult to keep the beam directed through the orifice if manual potentiometers are used. Also, keeping the beam aligned during the operation of aerodynamic facilities is frequently difficult because of mechanical vibrations and magnetic-field effects. For this reason, the author designed and built a feedback control device which keeps the beam aligned automatically. The feed-back control consists of detection plates which are placed above, below, and on either side of the orifice. If the beam misses the orifice, it strikes one of these plates. The collected current is fed through a resistance bridge between opposing plates into a Philbrick K2-XA operational amplifier wired as an integrator (see Figure 5). The output of the integrator controls the deflection of the beam so as to balance the resistance bridge. This centers the beam between opposing plates. Since there are two sets of plates surrounding the orifice, the beam is centered on the orifice. Calculated response time for the device is 50 microseconds, well within the frequency requirements of most disturbances.

V. OPTICAL SYSTEM

The test section has a plexiglass window to permit visual observation of the beam. A four-inch diameter, six-inch focal length glass lens was placed with its focal point on the beam. Behind this, a fifty per cent beam splitter

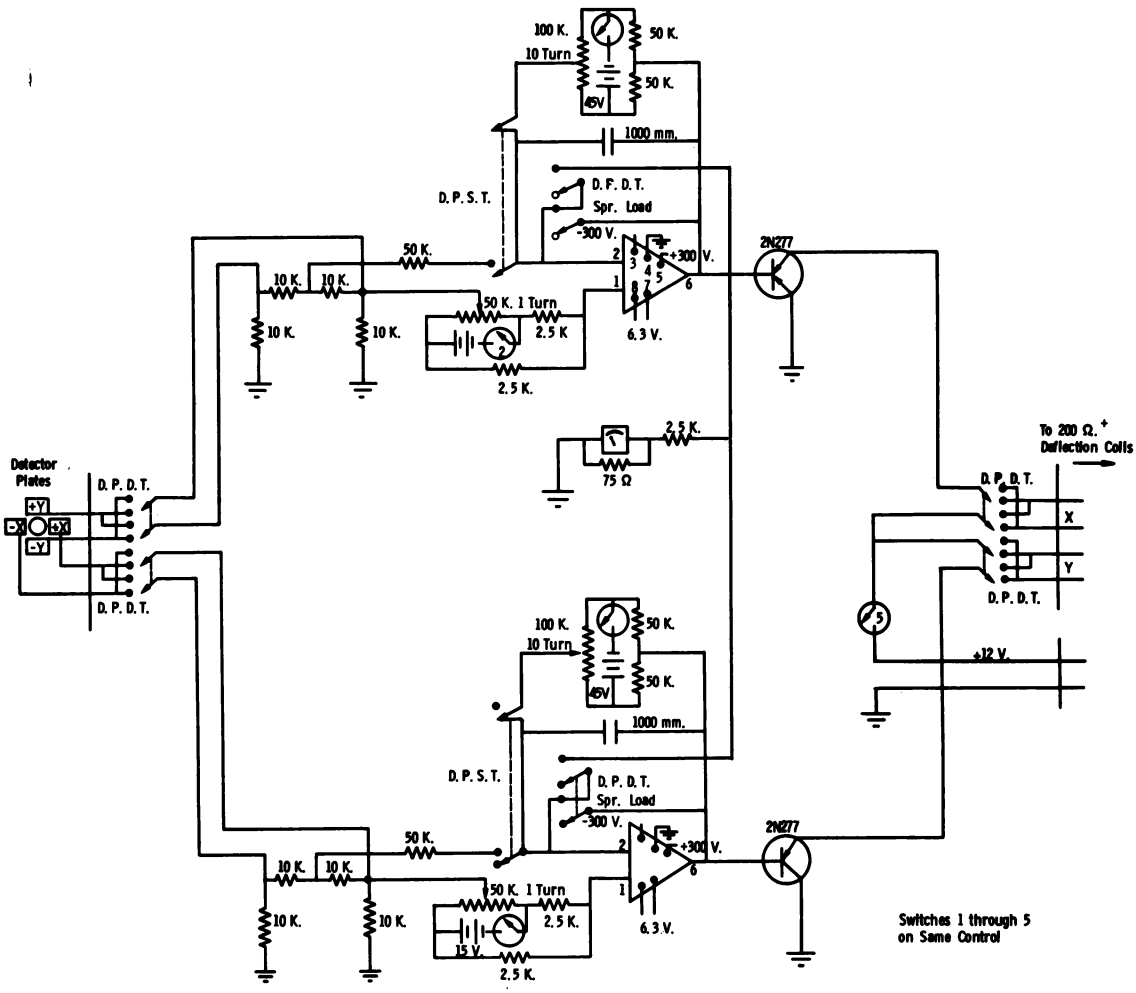

Figure 5. Electron beam controller circuit diagram.

was placed to divide the light between two spectrometers. Lenses similar to the first were placed in front of each of the spectrometers, with their focal points on the slits. When only one spectrometer is used, the beam splitter is removed allowing all of the light to fall on one spectrometer.

VI. SPECTROMETERS

Two types of spectrometers were used for this study: A Jarrell-Ash half-meter Ebert mount with an RCA 7265 photomultiplier; and a Bausch and Lomb quarter-meter with an RCA 6342A photomultiplier. Although extremely good resolution is available, it was not a critical factor. The slits were set at one hundred microns for most of this study unless otherwise indicated.

VIII. CRYOGENIC SYSTEM

In order to study the characteristics of the gases at low temperatures, a copper tank was constructed around the test section and thermocouples placed on the inner wall of the test section. The copper tank was filled with liquid nitrogen, which lowered the temperature of the gas sample to approximately $90^{o}K$. By letting the chamber warm to room temperature, the entire range of temperatures between $90^{o}K$ and $300^{o}K$ could be studied at constant pressure.

CHAPTER III

ELECTRON BEAM ATTENUATION

I. ATTENUATION IN AIR

When an electron beam traverses a gas there is an attenuation of the beam due to interaction with the molecules of the gas, both elastic and inelastic. The mechanism for this attenuation is considered to be Rutherford scattering in nature, but a literature search reveals that no analytical solution has been obtained. No matter what the mechanism, however, an approach similar to Lambert's Law can be used effectively. Assuming the electron energy to be constant along the path of the beam, the attenuation in a distance dx is

$$dI = -\mu I \, dx, \tag{1}$$

where I is the beam current, x is the distance along the beam, and μ is the linear absorption coefficient. Experimental data show μ not to be a function of current. At constant temperature, the coefficient is only a function of pressure and energy, so

$$\mu = \mu(P,E). \tag{2}$$

Therefore,

$$\mu(P,E) = - \frac{dI}{I\ dx} . \qquad (3)$$

When multiplied by one hundred, the above expression is the percentage attenuation per unit length of the beam, and is called the attenuation factor. This function, $\mu(P,E)$, can be experimentally determined with the system described herein.

The determination of $\mu(P,E)$ requires measuring the beam current at various positions with a catcher plate which is mounted on a movable shaft. The beam must not be allowed to drift while the measurements are being made. Beam currents were measured at one-inch intervals to a distance of six inches from the orifice. Test section pressure and electron beam current were varied over a wide range of values (see Figure 6).

The attenuation versus pressure is plotted in Figure 6. The accelerating potential was 10 KV and the temperature was 300°K. The attenuation factor was nearly thirty per cent per inch at pressures of 2 mm Hg, an unusable level for most studies. The values given by Muntz (2) for an accelerating potential of 35 KV are also shown in Figure 6 to indicate the variation in attenuation with electron energy. Accelerating voltages as high as those used by Muntz were

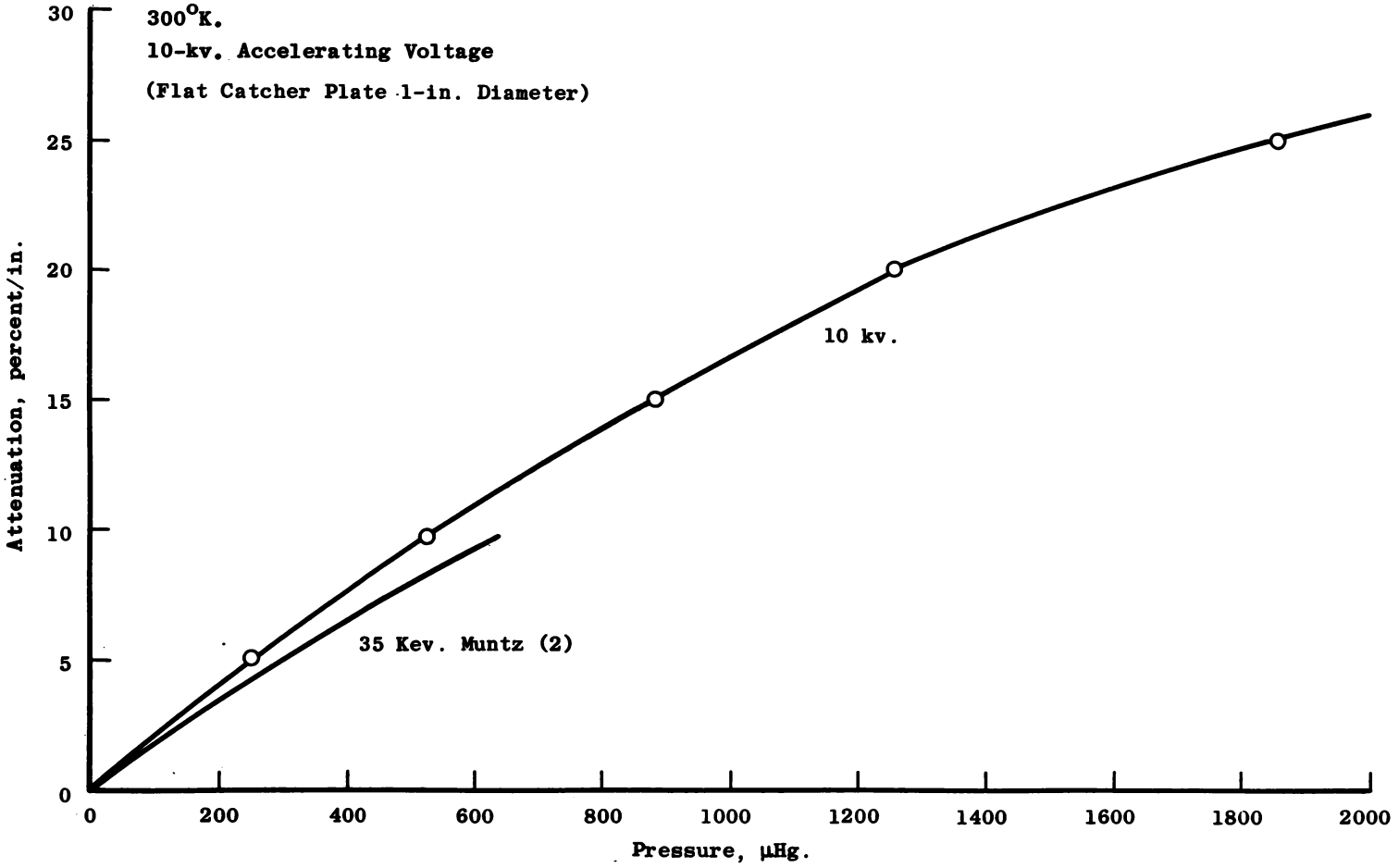

Figure 6. Percentage attenuation of the electron beam per unit length versus air pressure.

not used in this experiment. Normally such high potentials will not be used because of radiation hazards to personnel. However, in high-density gas applications these higher potentials are necessary.

It was expected that there would be a variation in μ with current, since the current tends to heat the gas in the beam, reducing the local density. The heating has since been shown by Petrie, Pierce and Bishburn (3) to be on the order of $0.5^{o}K$ per milliampere. The currents used in this experiment did not exceed one-half milliampere and thus the heating was negligible. If larger currents are used, there may be a noticeable effect.

In order to calculate the current remaining after a certain path has been traversed, the differential equation above is integrated, giving

$$I = I_{o}e^{-\mu(P,E)x}, \tag{4}$$

where I_{o} is the current at a reference point, usually the orifice, and x is the distance from the reference point. Using the above equation and the intensity-versus-current curves presented later, it is possible to determine the initial current necessary to produce a given current at a point in the test chamber. Also, the above equation can be used to determine the current at a given distance from the

electron beam collector. If the current at this point is known, the local gas density can be determined from the intensity of the radiated light. The beam collector used in this study was a flat plate. Therefore, the data given is representative of data taken with this type beam collector.

Beam attenuation methods for determining densities have an inherent weakness in that they give only an integrated value for the density and the differential values cannot be determined. This is sufficient if the density profile is known across the path, but in most cases a point density, as determined by light output intensity, would be much more useful.

As the pressure in the test section is increased, the beam has a noticeable spreading. Since the detector plate was only an inch in diameter, there was concern that the spreading would exceed the plate at higher pressures. The data indicates this happened at higher pressures because the value of μ was not constant over the entire path length. However, usable data were obtained up to 2000 μ Hg.

CHAPTER IV

STUDY OF HELIUM-AIR MIXTURES

A diagram of the shock tunnel is shown in Figure 7. A high-velocity, low-density test flow is generated by precharging the driven tube to a pressure which will yield the desired test section conditions. The driver section is then pressurized until a diaphragm separating the two sections is ruptured, initiating a compression shock in the driven tube gas. When this pressure rises sufficiently, a second diaphragm between the driven tube and the previously evacuated dump tank ruptures, causing a high velocity, low density flow to pass the test section area. The parameters of pressure, diaphragm thickness, etc., are predicted from shock tunnel theory and experiments.

In the process of determining the test section parameters of a shock tunnel, it is necessary to determine the duration of usable test flow as limited by the arrival of the test gas (driven tube gas) - driver gas interface. This is important to know because aerodynamic data taken after the arrival of the interface are invalid. In the majority of cases in the Arnold facility, and others, to date the driver gas has been helium and the test gas has

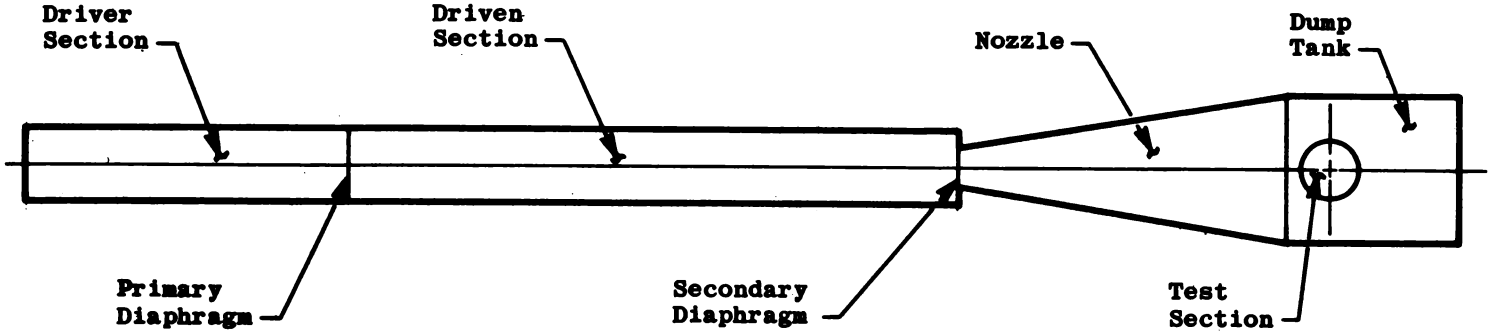

Figure 7. Diagram of a shock tunnel.

been air. However, increased requirements have necessitated the use of a hydrogen driver in many cases.

The electron beam excitation technique is quite applicable to the determination of the time-resolved species concentration of these gases in the test section. The development of this technique as an adequate interface detection system hinges upon understanding the interaction of the beam with the helium-air mixtures. Figure 8 illustrates beam attenuation data in helium-air mixtures obtained in this study. The gas mixtures were obtained by mixing proportional volumes in a high pressure bottle. This method gives a number density percentage of the gases, and was used consistently throughout the experiment. Additional work describing species concentration measurement is given in Chapter V.

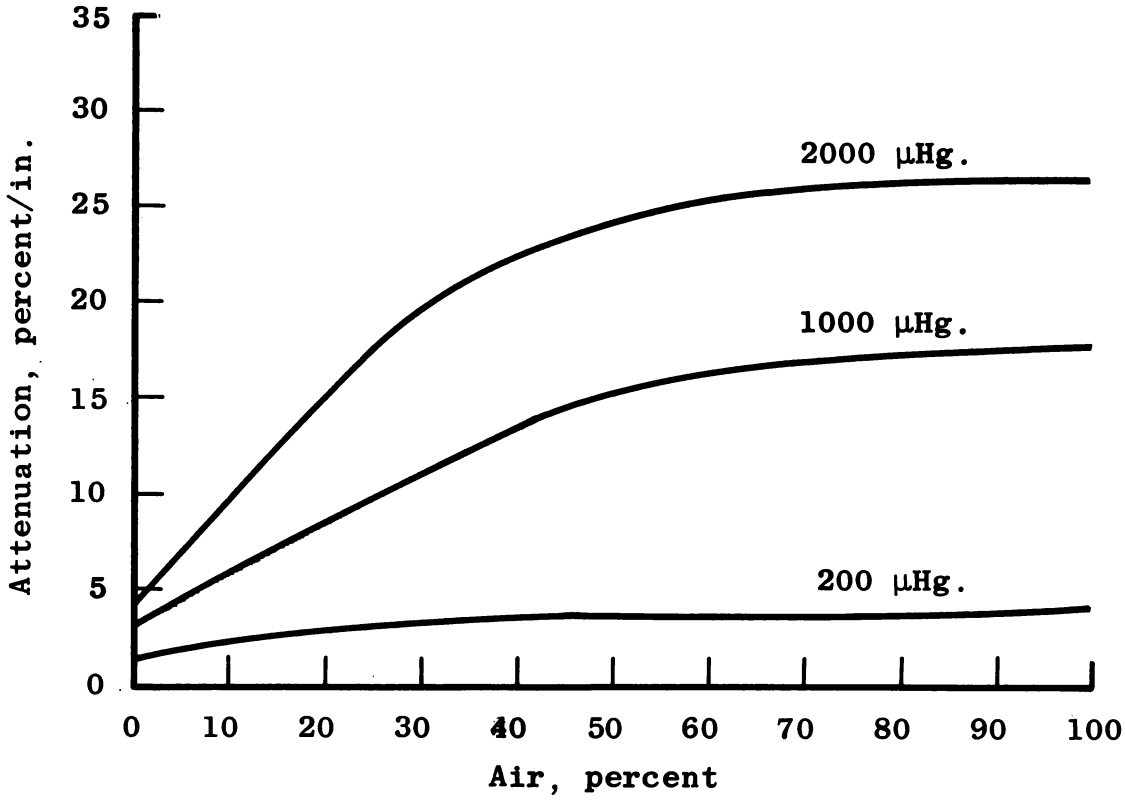

Figure 8. Attenuation in air-helium mixture.

CHAPTER V

SPECTRAL INTENSITY OF ELECTRON BEAM EXCITATION

For the study of the characteristics of a gas by the use of an electron beam, it is important to know the relative intensities of suitable spectral lines as a function of pressure and beam current. It might be expected that there would be a considerable change in intensity with beam energy. However, this is not the case, and it is shown in a report by Bauer and Bartkly (4) that for beam energies above a few hundred volts the ionization cross section for both helium and nitrogen is nearly constant. This is shown in Figure 9. Then, since the ionization cross section is not a function of energy, the number of molecules excited is not a function of energy and, therefore, the intensity of the line is independent of energy.

The first consideration is to determine the spectral lines in helium and bands in air that are suitable for diagnostic work. In helium the intense 5016 $\mathring{A}(2^1s - 3^1p)$ line would seem to be a good choice since it is sufficiently separate from other lines, and has a sufficiently short lifetime. The lifetime can be determined from an equation by Sebacher (5).

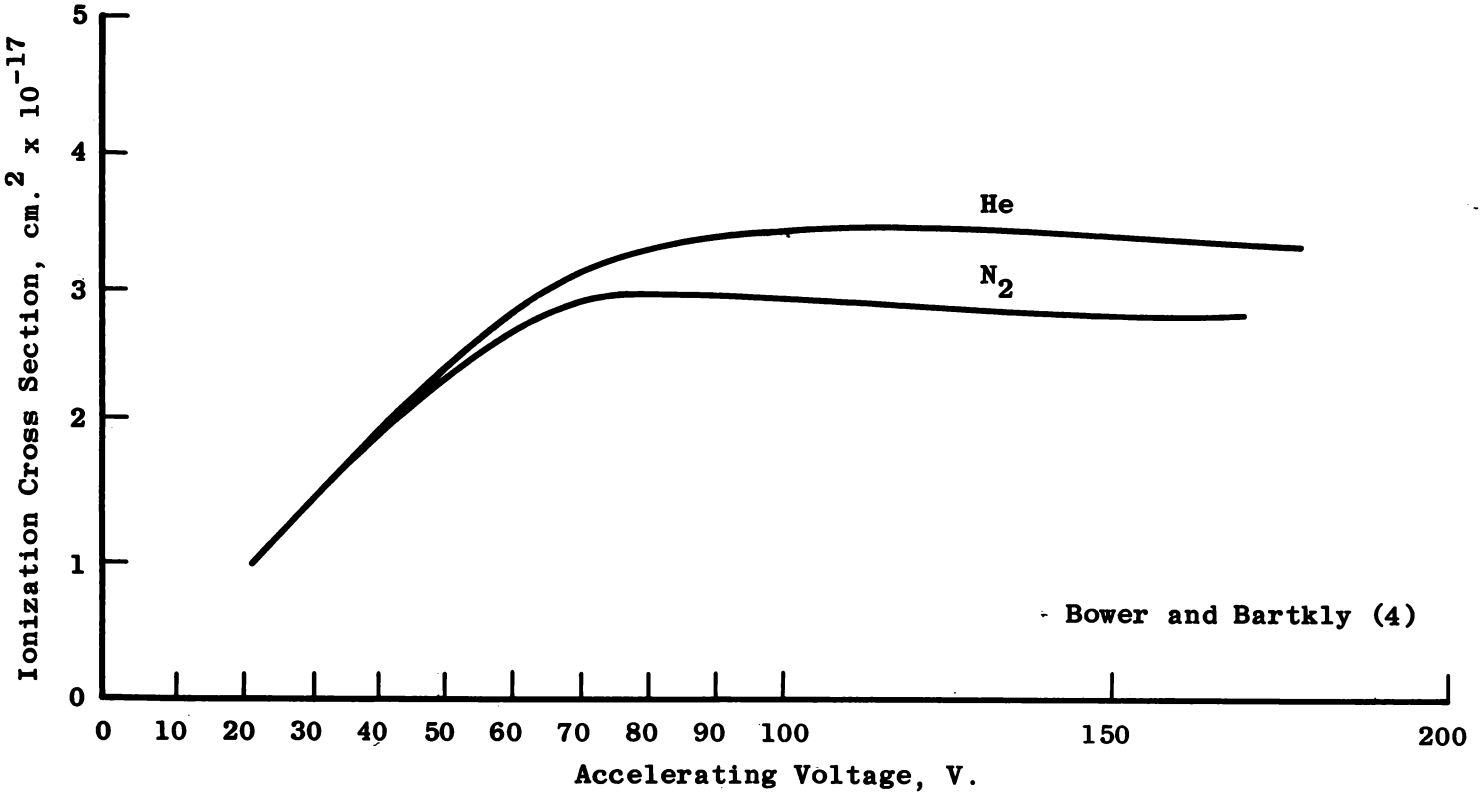

Figure 9. Ionization cross section for helium and ionization cross section for nitrogen.

If N_o atoms are excited to a reference level, then the number remaining in this level as a function of time is determined by the equation,

$$N = N_o e^{-gAt},$$

where A is the probability per unit time for emission (the Einstein Coefficient) of a quantum of resonance radiation from an isolated atom, and g is the imprisonment factor. The imprisonment factor is less than unity, and depends on density, the shape of the containing vessel, and the dimensions of the containing vessel.

The strong 5016 Å helium line ($2^1p - 3^1p$) indicates a considerable population of the 3^1p level, which has the choice of another transition (537 Å). This transition is a resonant one. Heron, McWhirter, and Roderick (6), using pure helium, have shown that the lifetime of the 3^1p level is determined largely by the phenomenon of imprisonment of resonance radiation, is pressure-dependent, and is of the same order of magnitude as the lifetimes measured for the 3914 Å ionized nitrogen band in a mixture of helium and nitrogen. The imprisonment is due to the fact that the 537 Å resonance photon has a large cross section for absorption by unexcited helium atoms, and can escape from the enclosure only after many absorptions and re-emissions.

The Einstein Coefficient (A) is the reciprocal of the mean lifetime of the resonance level in the absence of imprisonment. The imprisonment factor g as given by Holstein (7) is

$$g = \frac{1.60}{K_o R(\pi \ln K_o R)^{1/2}} , \tag{5}$$

where R is the radius of the containing vessel and, for a Doppler-broadened line, K_o is

$$K_o = \frac{\lambda^3 n}{8\pi} \frac{g_2}{g_1} \frac{A}{V_o \pi} , \tag{6}$$

where V_o is the most probable thermal velocity of a helium atom,

$$V_o = \sqrt{\frac{2kT}{M}} , \tag{7}$$

n is the number of unexcited helium atoms per cubic centimeter, and g_1 and g_2 are the statistical weights of the resonance and ground levels respectively.

In the case of the electron beam, the excited states are produced at a rate Q_o per unit time, the rate depending mainly on electron current. The total number excited in dt is $Q_o dt$. The intensity of the 5016 Å line can be expressed

$$I_{5016} = h\,\nu_{5016}\,N_{3^1p}\,A_{3^1p-2^1s} \tag{8}$$

and

$$I_{5016}(t) = h\,\nu_{5016}\,N_{3^1p}(t)\,A_{3^1p-2^1s}. \tag{9}$$

The incremental number dN of atoms remaining in the resonant state due to the number of atoms excited in interval dt is

$$dN = Q_o dt\, e^{-g'A't} = N_o\, e^{-g'A't}\, dt\ . \tag{10}$$

It follows

$$N(t) = \int_o^N dN = \int_o^t Q_o e^{-g'A't}\, dt, \tag{11}$$

$$N(t) = \frac{Q_o}{g'A'}\,(1 - e^{-g'A't})\ . \tag{12}$$

In the case of the 3^1p state g'A' involves both the 5016 Å transition and the 537 Å transition, but only the 537 Å is resonant and has an imprisonment factor (see Figure 10); therefore,

$$g'A' = gA_{537} + A_{5016} = \frac{1}{\tau 3^1p}\ . \tag{13}$$

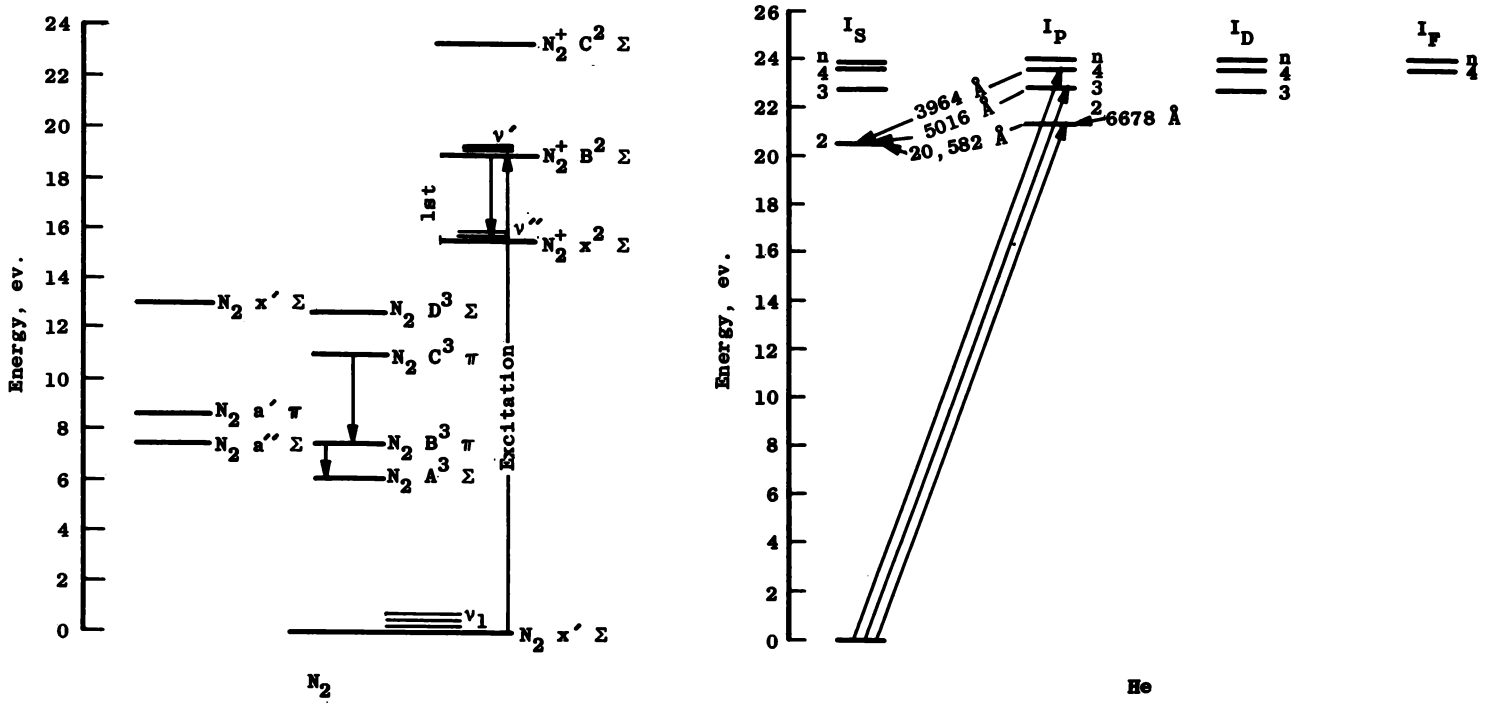

Figure 10. Energy level diagram for helium and nitrogen.

Thus

$$N_{3^1p}(t) = \frac{Q_o}{gA_{537} + A_{5016}} \left[1 - e^{-(gA_{537}+A_{5016})t}\right]. \quad (14)$$

Substituting,

$$I_{5016}(t) = h\nu_{5016} \frac{Q_o A_{5016}}{gA_{537} + A_{5016}} \left[1 - e^{-(gA_{537}+A_{5016})t}\right]. \quad (15)$$

For example, assume the following representative values taken from Heron, McWhirter, and Roderick (6):

$$A_{5016} = 1.35 \times 10^7 \text{ sec}^{-1}, \quad (16)$$

$$A_{537} = 5.6 \times 10^8 \text{ sec}^{-1}, \quad (17)$$

$$\nu_{5016} = .99 \times 10^{15} \text{ Hertz}. \quad (18)$$

Rearranging

$$I_{5016}(t) = \frac{K}{gA_{537} + A_{5016}} \left[1 - e^{-(gA_{537}+A_{5016})t}\right], \quad (19)$$

where $K' = K \times 10^{-7}$,

$$I_{5016}(t) = \frac{K'}{56g + 135} \left[1 - e^{-(56g+135)\times 10^7 t}\right]. \quad (20)$$

As g goes from unity to zero, pressure goes from zero to infinity. From this, it is seen that after 1×10^{-8} seconds 99.68 per cent of the maximum radiated light intensity will be realized, making this line suitable for use in measuring the characteristics of a high velocity aerodynamic flow. The 4278 $\mathring{A}$ N_2^+ band radiation has a decay time of the same order of magnitude and is furthermore not affected by resonance.

Since the helium line under study is an atomic line, intensity under the conditions of this experiment will not be a function of temperature, but the line under study in nitrogen is a molecular band and subject to changes with temperature.

Since it is known that there will be a large effect on intensity by temperature in the R branch of the vibrational band, only the P branch with band head at 4278 $\mathring{A}$ was used for this study.

The intensity of a P branch line is given by Muntz (8) as

$$I_p = X_4 \nu_p^4 \frac{K' + 1}{2K' - 1} \left[(K' + 1)\, e^{-B_{v1}''(K'-1)(K'+2)\frac{hc}{kT_R}} + K'\, e^{-B_{v1}''(K')(K'-1)\frac{hc}{kT_R}} \right], \qquad (21)$$

where

X_4 is only a function of N_2 number density,

ν_p is the wave number of a line in the P branch,

K' is the rotational quantum number,

B_{v1}" is the rotational constant corresponding to the V_1" vibrational level,

T_R is the rotational temperature of N_2,

h is Planck's constant,

k is the Boltzmann constant, and

d is the speed of light.

By evaluating the ratio of the sum of the intensity of the P branch at 20^o and 300^oK it is found that the ratio is

$$\frac{I_{20^o}}{I_{300^o}} = .95. \tag{22}$$

Thus the intensity variation with temperature is not enough to have any effect on the studies for this report.

The validity of this is demonstrated later in the experimental data. No temperature effect was detected from 88^o to 300^oK.

The curves presented in Figures 11 through 14 are of the relative intensity of the P branch of the 4278 Å nitrogen

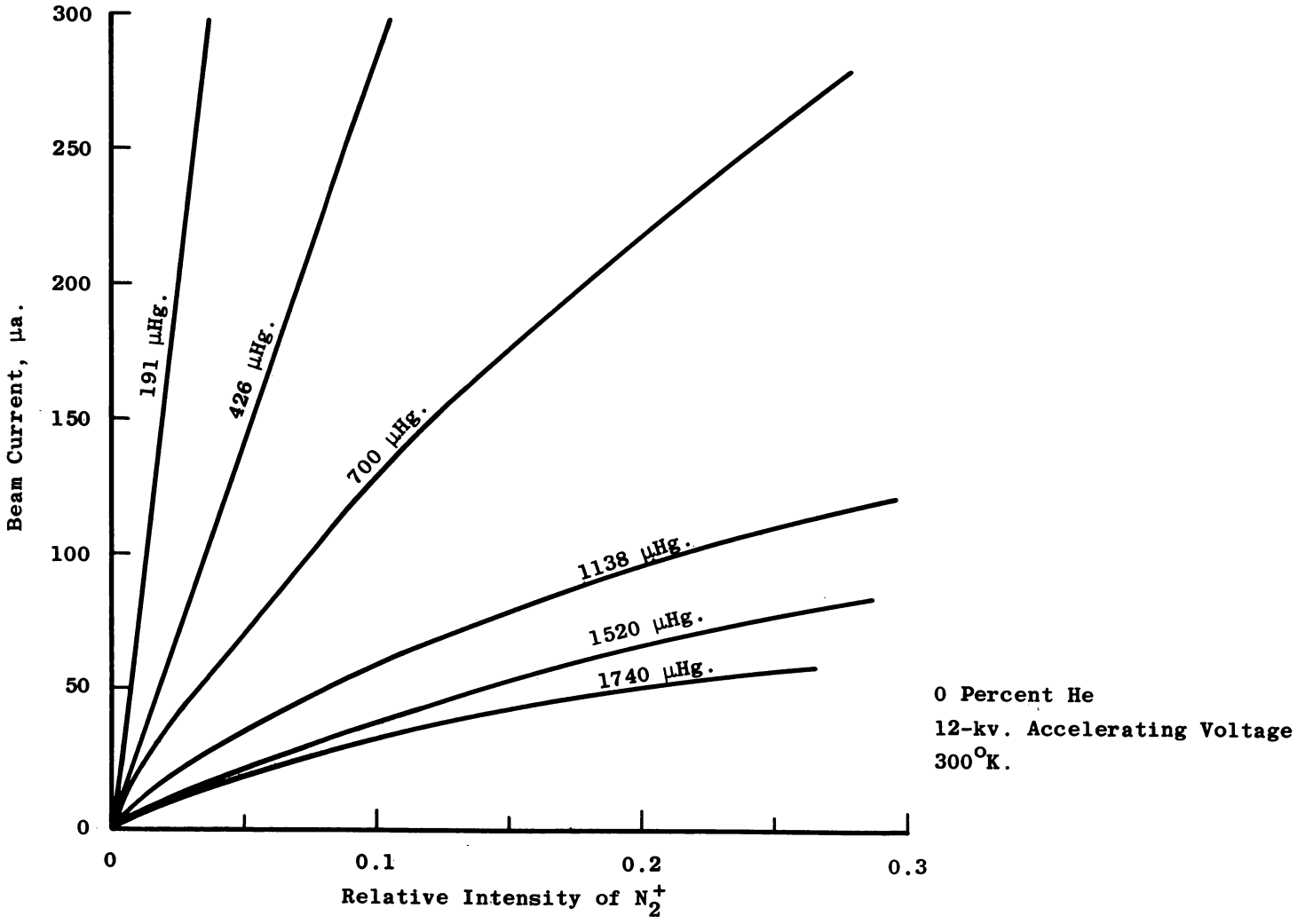

Figure 11. Beam current versus intensity of the 4278 Å N_2^+ band for pure air.

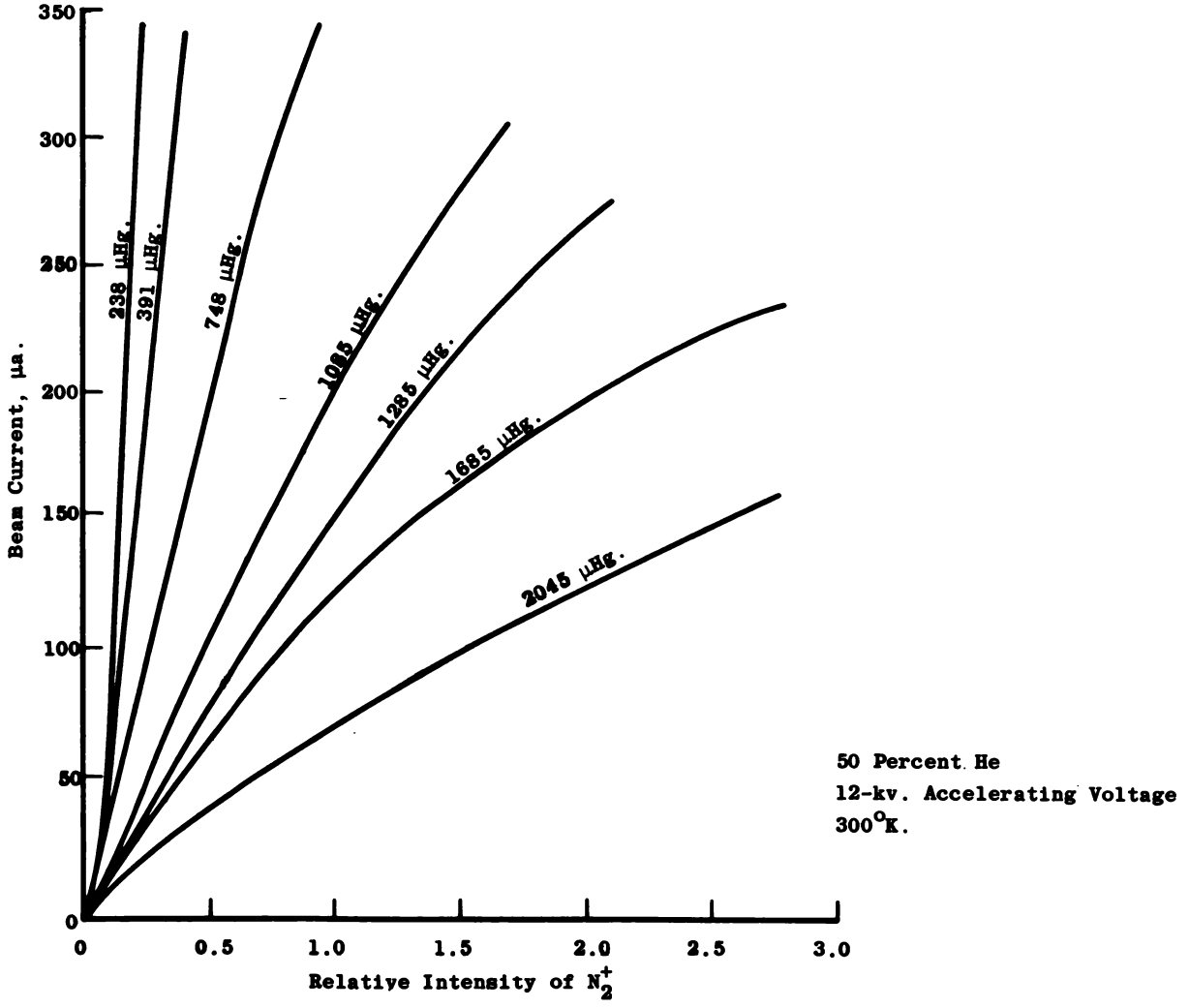

Figure 12. Beam current versus intensity of the 4278 Å N_2^+ band for 50% helium.

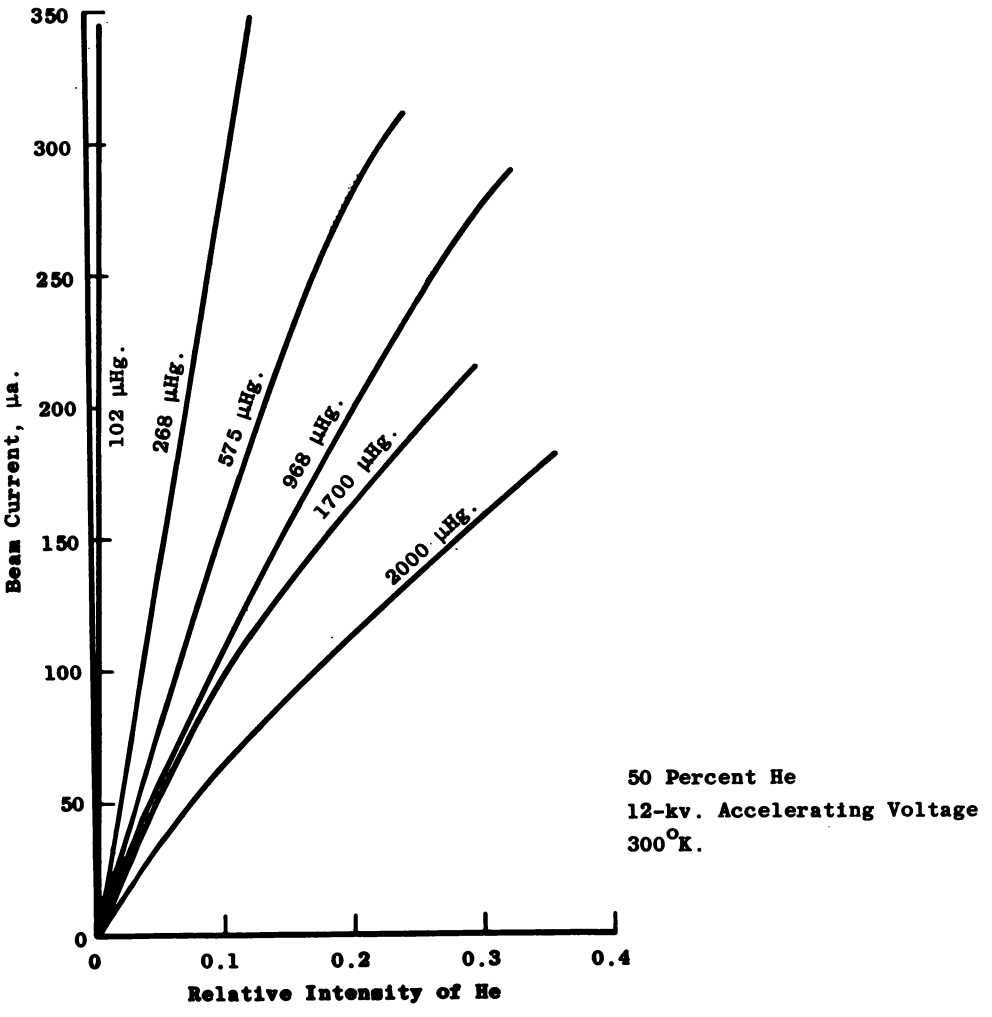

Figure 13. Beam current versus intensity of the 5016 Å He line for 50% helium.

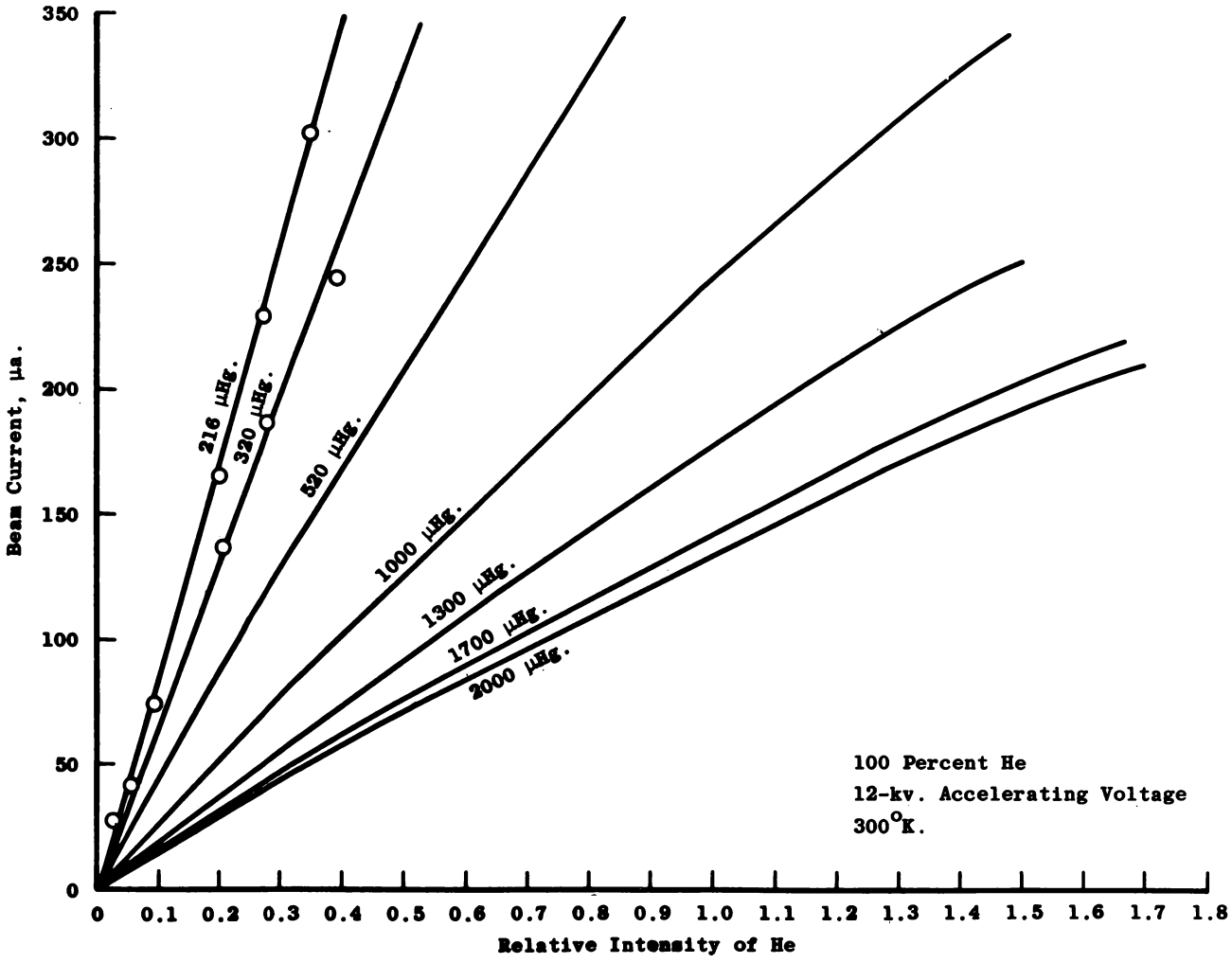

Figure 14. Beam current versus intensity of the 5016 Å He line for 100% helium.

band and the 5016 Å helium line. These data were taken in pure samples of the respective gases and in a 50 per cent mixture.

The line intensity study in a mixture was done to check for possible interaction between the gases. There was no observed effect. The conversion of the photomultiplier output voltage (expressed as relative intensity) into absolute intensity could be done with the aid of a standard lamp which replaces the beam under the same geometrical conditions. This would allow conversion to absolute energy output, and since it is known what volume is being observed, the specific voltage output could be determined. The curves were made for both air and helium over a wide range of pressure and beam current. With the exception of a few of the curves, which have data points plotted, the graphs are smoothed traces of curves taken from an "X-Y" plotter. From these curves, intensity versus pressure at constant current can be deduced, and are presented in Figures 15 through 18 for completeness.

With these curves, the density at a point near a small model can be determined if the model is designed such that it is a suitable electron beam collector. By directing the beam onto the model, measuring the optical intensity at a point close to the model, and collecting the beam on the

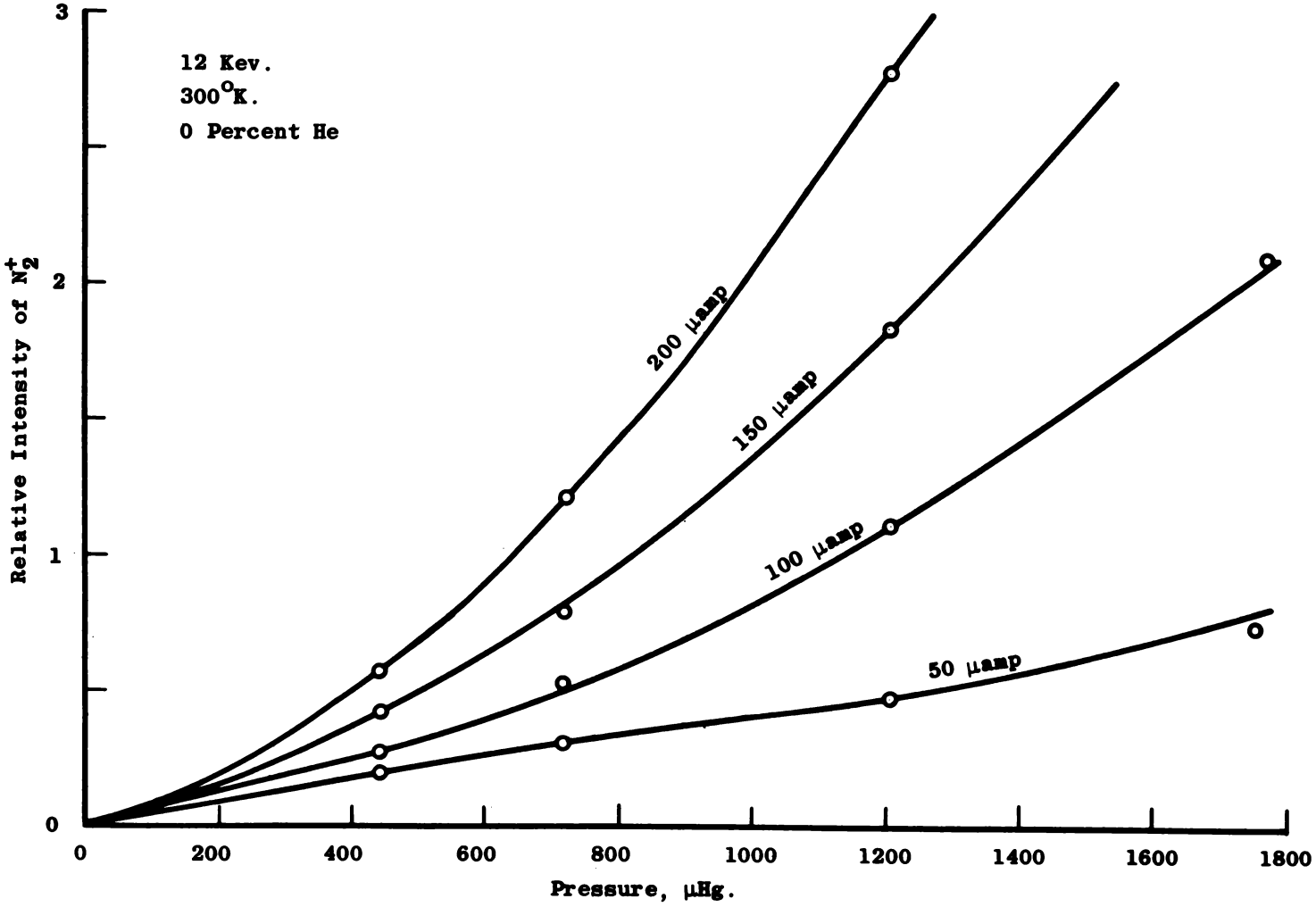

Figure 15. Intensity of the 4278 Å N_2^+ band versus pressure for pure air.

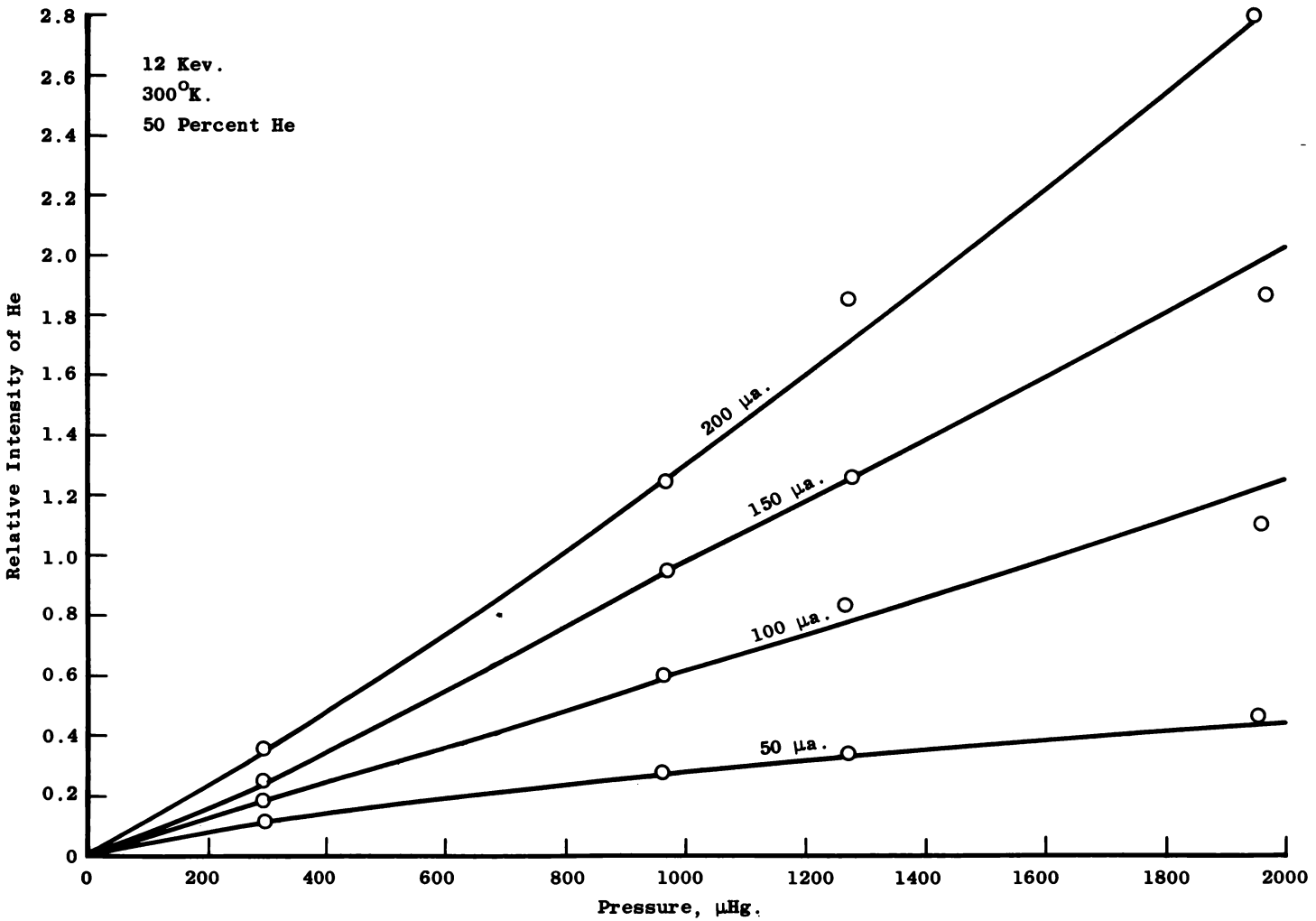

Figure 16. Intensity of the 4278 Å N_2^+ band versus pressure for 50% helium.

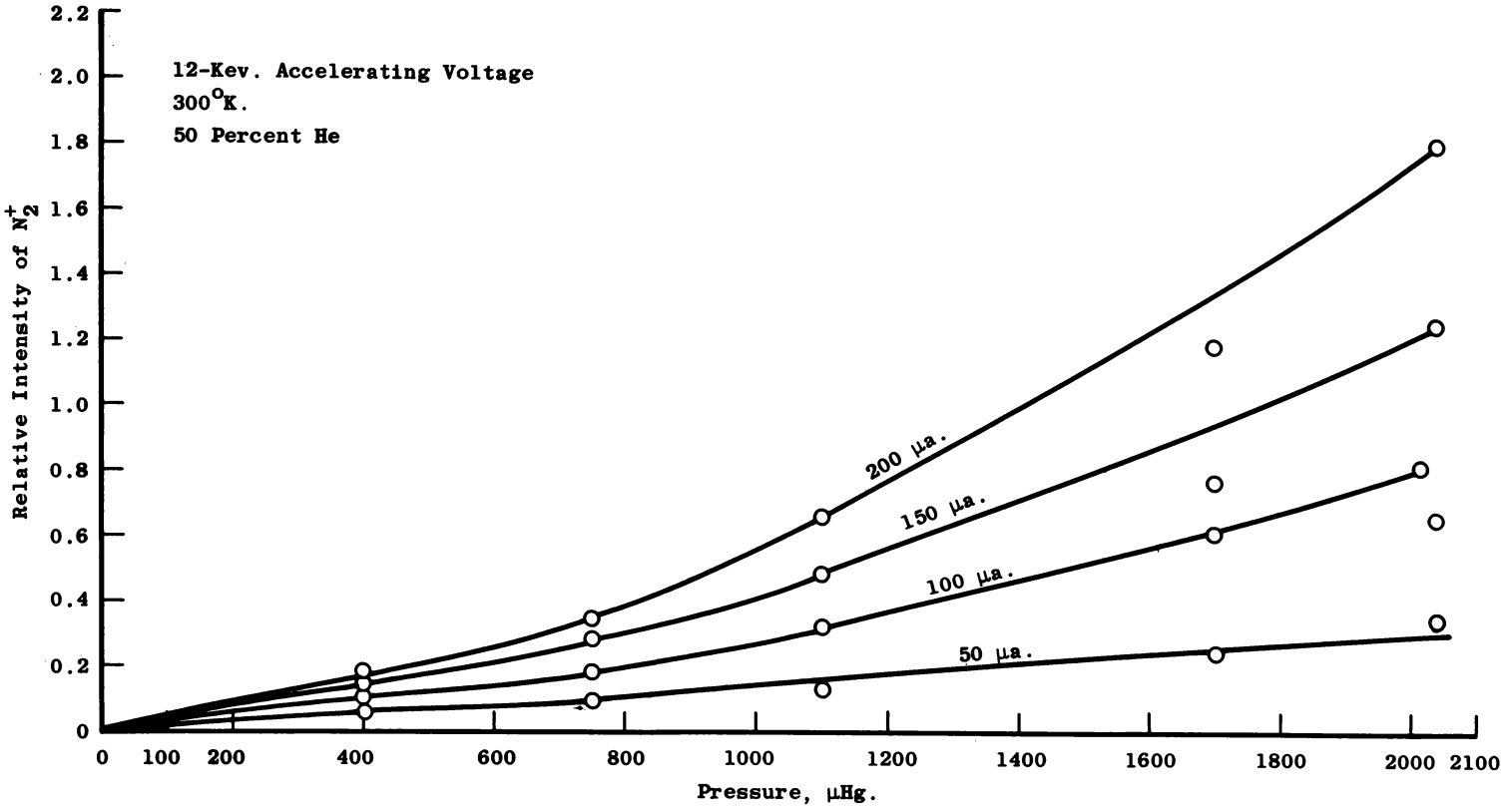

Figure 17. Intensity of the 5016 Å He line versus pressure for 50% helium.

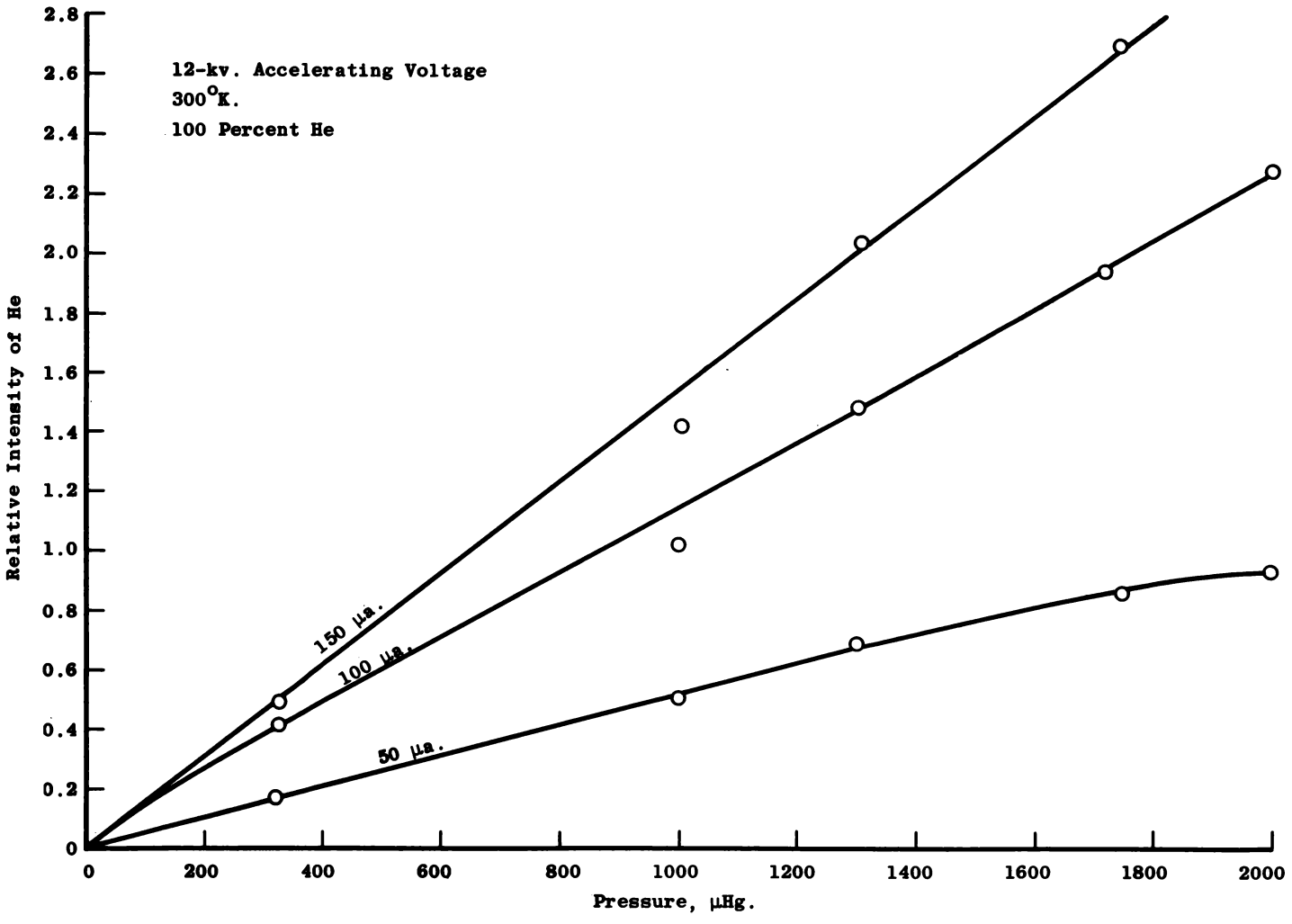

Figure 18. Intensity of the 5016 Å He line versus pressure for 100% helium.

model, the density can be determined without disturbing the flow.

There has been considerable discussion by Gadamer (9) of possible collision quenching of the beam excited intensity at higher densities (above one millimeter at room temperature). This effect is caused by the loss of energy of the excited molecules by collision rather than by photon emission. Over the range of variables used in this study, no significant effect was detected.

CHAPTER VI

INTENSITY RATIO IN HELIUM-AIR MIXTURES

The ratio of the intensities of the 4278 $\mathring{A}$ band of N_2^+ and the 5016 $\mathring{A}$ line of helium in helium-air mixtures was studied for the purpose of measuring the relative concentration of the gases in a high-velocity shock tunnel test section. By focusing the optics on a small section of the beam, the ratio can be determined at a point with microsecond response time. Minimum response time is limited by the photon flux. If the number of photons observed is statistically inadequate, a ratio cannot be determined.

In this study, the intensity of the nitrogen and helium lines at a point along the beam were measured with two monochrometers and plotted on the two axes of an "X-Y" plotter. This ratio has been examined over a wide range of beam current, beam energy, pressure and temperature. The primary purpose of studying the ratio under all these conditions is to evaluate the influencing variables, and determine whether or not the intensity ratio is a function only of mixture ratio.

The beam current was varied from 0 to 500 microamps, the pressure from 50 to 2000 microns Hg, and the temperature from 88°K to 300°K. Two beam energies, 10KV and 15KV, were

investigated. By setting both spectrometers on the same spectral line and adjusting the gain of the output circuits, a one-to-one detection sensitivity was achieved so that the relative intensity could be measured directly.

It was found that there are no significant variations in the intensity ratio with any of the parameters except mixture ratio. It is apparent that for the purpose of determining species concentration in a dynamic system this technique is independent of the above environmental parameters.

In order to assess the theoretical validity of the experimental results described above, a first-order analysis of the electron beam interaction with the gas mixture was undertaken.

According to Dalton's law of partial pressures, each gas in a mixture of gases exerts pressure in proportional part by volume. Therefore, in a fixed volume mixture with 15 psia of air and helium, giving a total pressure of 30 psia, nitrogen exerts 39.5 per cent of the pressure (11.8 psia), oxygen 10.5 per cent (3.2 psia), and helium 50 per cent (15 psia). The error in neglecting the minor constituents of air is considered negligible since it is varied in nature and in any case does not exceed 5 per cent. While it is more convenient to measure pressure, the radiation from the gas (due to electron excitation) is proportional to

gas density, for a first-order analysis. Thus any theoretical calibration curve must be derived on the basis of density.

Utilizing the ideal gas law, a relation for the density is obtained:

$$\rho = \frac{PM}{RT}$$

where

P = pressure (partial pressure in this case),

M = molecular weight,

R = ideal gas constant, and

T = temperature.

Any consistent set of units is satisfactory in this case, since the ratio of two like quantities will always be alike. Finally, calling the total pressure P_T, the relation for the density of gas Y is

$$\rho_Y = \frac{P_T \, M_Y (\%Y)}{RT} \quad . \qquad (23)$$

The ratio of two gas densities at the same temperature is

$$\frac{\rho_X}{\rho_Y} = \frac{(\%X)M_X}{(\%Y)M_Y} \quad . \tag{24}$$

Taking the two gases to be helium and nitrogen we obtain the following relation,

$$\frac{\rho_{He}}{\rho_{N_2}} = \frac{1}{7}\,\frac{\%\ He}{\%\ N_2} \quad . \tag{25}$$

For a first-order analysis, the radiation due to electron excitation is directly proportional to gas density. Therefore, we may write the following equation for the intensity of radiation:

$$I_{He} = K_{He}\rho_{He} \quad , \tag{26}$$

$$I_{N_2} = K_{N_2}\rho_{N_2} \quad . \tag{27}$$

The ratio of intensities after substituting the density ratio becomes

$$\frac{I_{He}}{I_{N_2}} = \frac{1K_{He}}{7K_{N_2}}\,\frac{\%He}{\%N_2} \quad , \tag{28}$$

or in terms of helium percentage,

$$\frac{I_{He}}{I_{N_2}} = \frac{K \% He}{100 - \% He} , \tag{29}$$

where

$$K = \frac{1}{7} \frac{K_{He}}{K_{N_2}} . \tag{30}$$

Thus the ratio of helium radiation to nitrogen radiation may be written as a simple function of helium percentage multiplied by a constant. This function is plotted with experimental data in Figure 19. The constant may also include optical and electronic gain constants. Then the ratio of instrumentation outputs can be used to indicate helium percentage directly. In addition, this allows an entire function for helium percentage to be generated from a single calibration point.

From the experimental data in Figure 20, page 47, it is shown that the intensity ratio is directly proportional to the mixture ratio:

$$\frac{I_{He}}{I_{air}} = K_o \frac{\% He}{\% air} . \tag{31}$$

The proportionality constant K_o has a value of 0.34 for these two particular lines and the associated system.

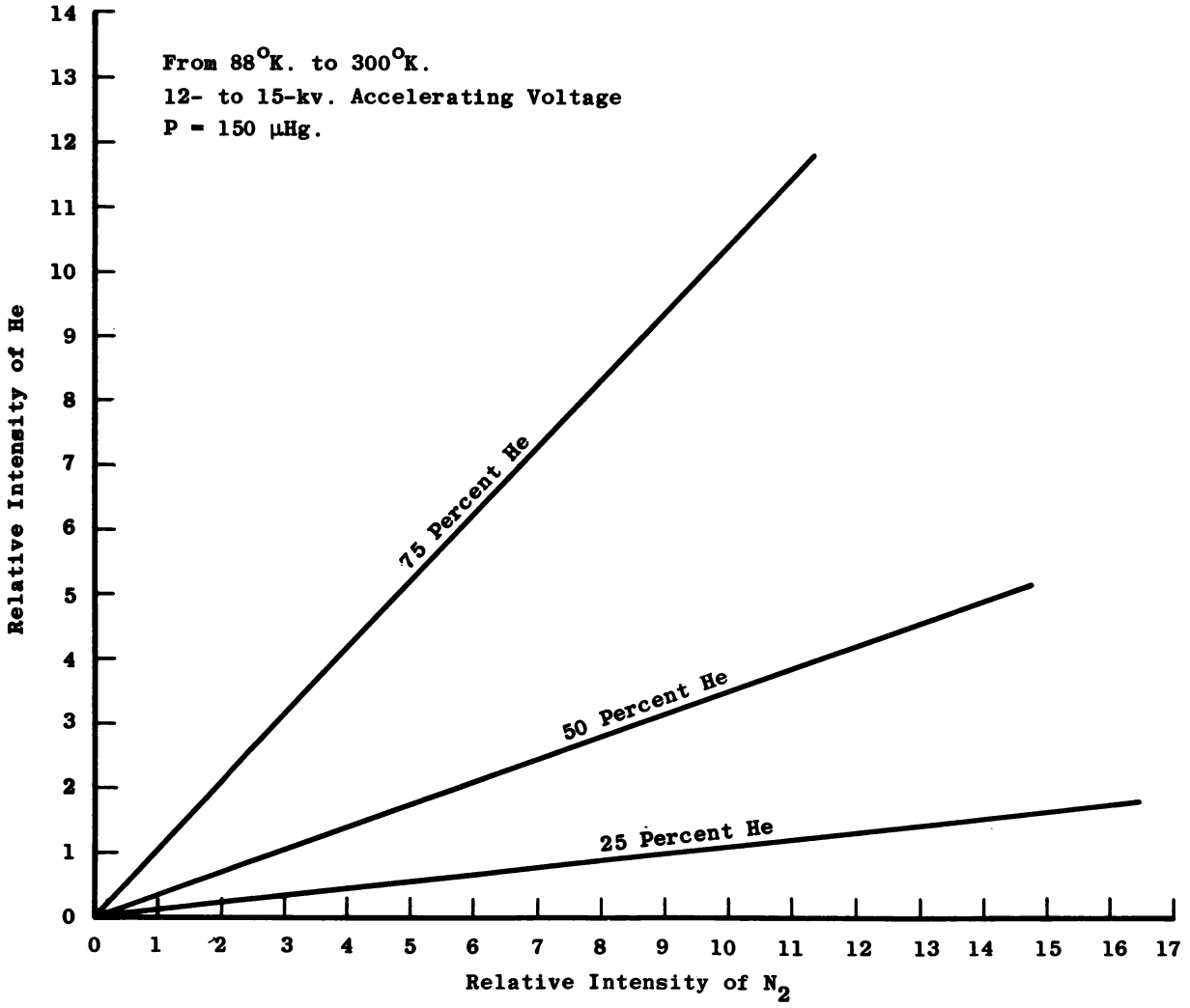

Figure 19. Intensity of air versus helium at various mixture ratios.

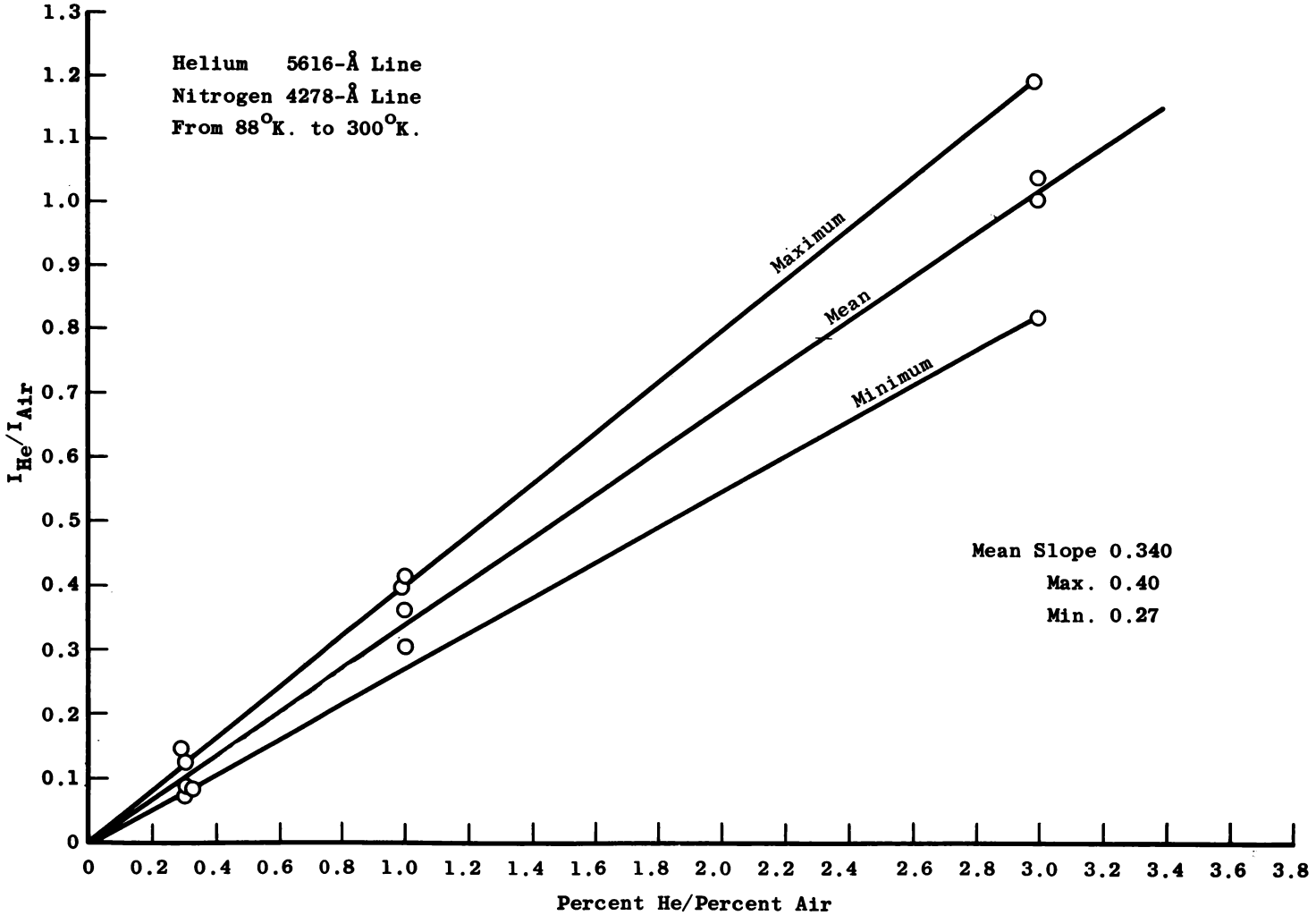

Figure 20. Mixture ratio %He/%Air versus I_H/I_A.

This ratio was studied from 88° to 300°K and although there was large intensity increase at low temperatures due to the increased density (Figure 21), there was no change in the ratio. This justifies the earlier derivation of the small temperature effect on the P branch of the molecular band of N_2.

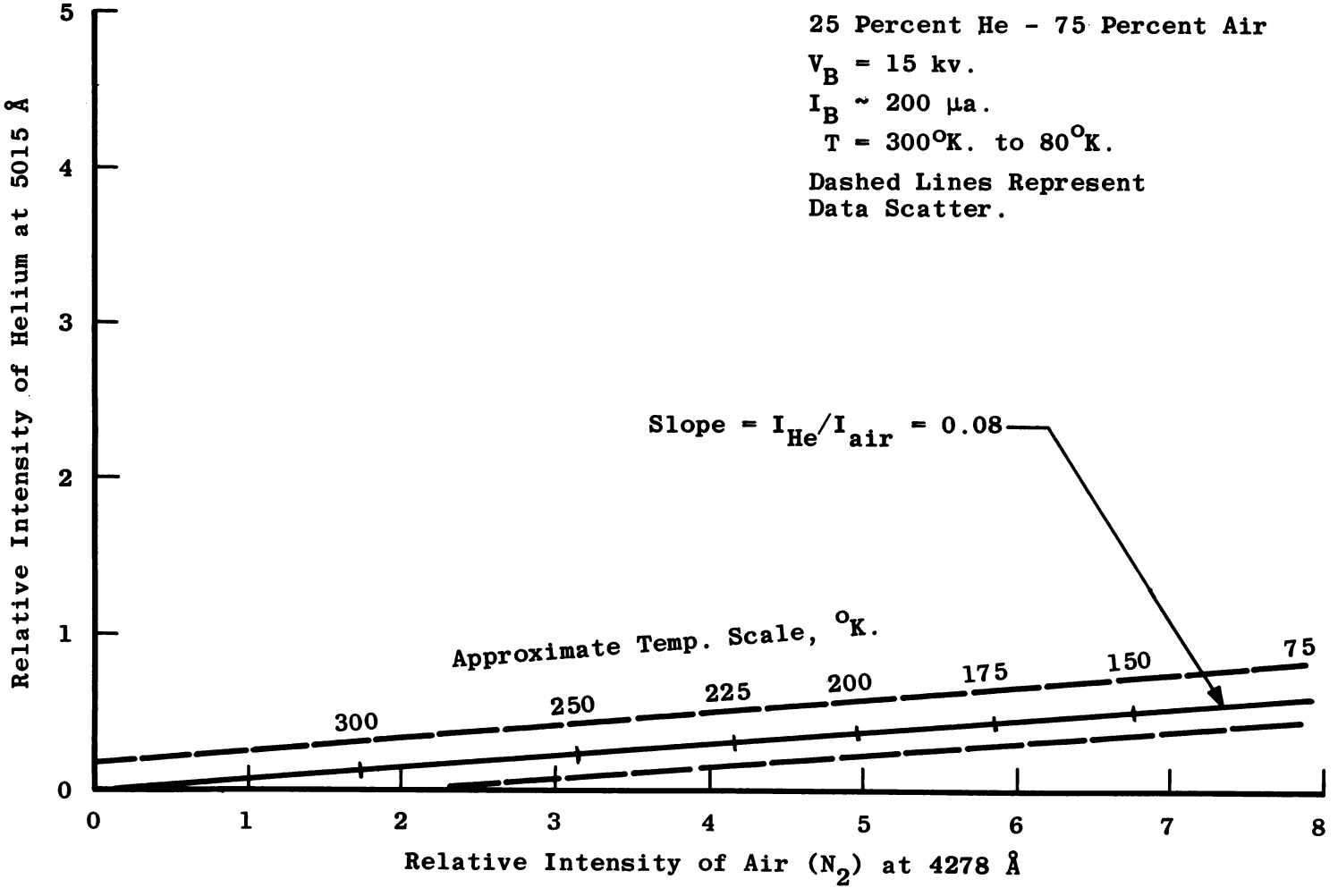

Figure 21. Intensity of air versus helium for 10° He from 88° to 300°K.

CHAPTER VII

SUMMARY AND SUGGESTIONS FOR FUTURE WORK

I. SUMMARY

The purpose of this investigation was to study the interaction of a 10 to 15 KV electron beam with helium and air and helium-air mixtures. It was necessary to develop equipment and determine the most predominate factors involved in the interaction. Several experiments were conducted concerned with the parameters of temperature, accelerating energy, beam attenuation, intensity output, and mixture ratio of two gases.

It was found that in helium and air, current had no effect on beam attenuation, that beam energy in the range from 10 to 15 KEV had no effect on the intensity output, and that temperature had negligible effect on beam intensity output in the P branch of the 4278 $\mathring{A}$ N_2 band. It was also found that the ratio of the intensities of the 5016 $\mathring{A}$ He line and the 4278 $\mathring{A}$ N_2 P branch was directly proportional to the mixture ratio of the two gases.

II. SUGGESTIONS FOR FUTURE WORK

A similar study as this should be undertaken using hydrogen instead of helium. This knowledge will soon be of equal importance in aerodynamic studies.

Studies at higher energies and pressures should be done. There is less attenuation of the beam at higher energies, and density studies using it as high as one atmosphere may be feasible.

Another possibility to be developed in connection with rapid detection of changing mixture ratio is "seeding." A marker gas which has a usable spectral line can be mixed with a gas that does not in order to study the mixing.

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BIBLIOGRAPHY

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