THE OMEGATRON IN ULTRA HIGH VACUUM

PARTIAL PRESSURE ANALYSIS

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ABSTRACT

The operating parameters for the omegatron were defined for pressures from 10^{-6} torr to less than 10^{-10} torr. The sensitivity and resolution of the omegatron were determined for helium, nitrogen, argon, and carbon dioxide. The measured resolution was compared with the theoretical resolution and the sensitivity was compared with the sensitivity of the Bayard-Alpert type ionization gage. Data are presented to show that the operating parameters are independent of the pressure from 10^{-6} torr to 10^{-10} torr.

INTRODUCTION

In most experiments conducted in the ultra high vacuum range it is essential to know the partial pressure of each gas surrounding the experiment. In working with so called "clean surfaces," for instance, it is necessary to know which gases are adsorbing on the clean surface. To take a more general example, if the pressure is measured with an ionization gage the composition of the gas must be known because an ionization gage has a different sensitivity for each gas. An instrument that will give a quantitative as well as qualitative analysis of the gases in the ultra-high-vacuum range is known as an omegatron.

The omegatron was first proposed by Hipple, Sommer, and Thomas (ref. 1) as a device for accurately determining the value of the Faraday. A later paper by these authors (ref. 2) showed that the omegatron could be used to measure e/m ratio of gases present in a vacuum system. One of the earliest applications of the omegatron as a partial pressure analyzer was by Alpert and Buritz (ref. 3). They utilized a simplified version of the omegatron to show that helium was the predominant residual gas in their glass ultra-high-vacuum system. Many authors (refs. 4, 5, 6, and 7) have since then investigated different configurations of the omegatron in the pressure range around 10^{-6} torr. Very little work, however, has been done to investigate the operating parameters of the omegatron in the pressure range below 10^{-6} torr. It is the purpose here to define these parameters in the ultra high vacuum range and to determine the sensitivity of the omegatron for certain gases in this pressure range. This investigation was conducted on a simplified version of the omegatron based on the design of Alpert and Buritz (ref. 3).

CHAPTER I

PRINCIPLE OF OPERATION AND THEORY

The principle of operation of the omegatron is similar to that of a cyclotron. As shown in figure 1, an electron beam which is parallel to the magnetic field produces the ions inside the ionization chamber. The ions formed then interact with the crossed magnetic and alternating electric fields and are accelerated in orbits of increasing size. If the frequency of the applied RF voltage is the same as the cyclotron frequency of some particular e/m ratio, the ions with that particular e/m ratio will eventually strike the collector. A positive trapping voltage is applied to the sides of the ionization chamber to prevent the plane of the ion orbits from drifting away from the center of the ionization chamber and striking the sides of the ionization chamber.

There are several theoretical treatments of the motion of ions in an omegatron in the literature (refs. 8 and 9). Some useful parameters are given below.

An expression for the radius of the orbit of an ion in the omegatron is

$$r = \frac{E_o}{B\epsilon} \sin \frac{\epsilon t}{2} \qquad (1)$$

where E_o is the amplitude of the RF field, B is the magnetic field strength, t is the time measured after the ion is formed and

$$\epsilon = \omega - \omega_c \tag{2}$$

In the above expression ω is the angular frequency of the alternating RF field and ω_c is the cyclotron angular frequency of an ion with a particular e/m ratio given by

$$\omega_c = \frac{eB}{m} \tag{3}$$

where e is the electronic charge in emu and m is the mass of the ion in grams.

If the frequency of the RF field approaches the cyclotron frequency of a particular ion, in other words as $\epsilon \to 0$, then that particular ion approaches its resonant condition and if $\epsilon \to 0$ in equation (1) the radius of the resonant ion orbit is given by

$$r_c = \frac{Eo\ t}{2B} \tag{4}$$

where r_c is the radius of the resonant ion orbit at time t. Thus the radius of the resonant ion orbit increases uniformly with time and the path of the resonant ion is an Archimedes' spiral.

There are nonresonant ions present in the omegatron whose cyclotron frequency is very close to the RF frequency and some of these ions will also be collected. There is a range of cyclotron frequencies, therefore, that will be near enough to the RF frequency that ions with cyclotron frequencies that fall within this range will also be collected. This range of frequencies can be evaluated by considering equation (1). From equation (1) if the collector is located a distance r_o from the electron beam, the ion with a cyclotron frequency ω_c will never reach the collector if

$$r_o > \frac{Eo}{B\epsilon} \tag{5}$$

There is, then, a critical value of ϵ for which the ions will reach the collector given by

$$\epsilon' = \frac{Eo}{r_o\, B} \tag{6}$$

Thus an ion with a cyclotron frequency of ω_c will be collected if

$$\omega - \omega_c \leq \frac{Eo}{r_o\, B} \tag{7}$$

The resolution of the omegatron is defined as

$$R = \frac{\omega_c}{2\epsilon'} = \frac{e\, r_o\, B^2}{2Eo\, m} \tag{8}$$

In practical units $R = \dfrac{48 r_o\, B^2}{Eo\, M}$ where r_o is in centimeters, B is in kilogauss, Eo is in volts per centimeter, and M is in atomic mass units. The resolution can be measured experimentally because the $2\epsilon'$ term in equation (8) is the width of the resonant ion peak measured at the base of the peak.

The length of an Archimedes' spiral is approximately equal to the number of revolutions times the average orbit circumference. The path length of the resonant ion as it spirals to the collector is thus given by

$$\lambda = n\pi r_o \tag{9}$$

where n is the number of turns made by the resonant ion prior to being collected. From equation (3)

$$\omega_c = \frac{eB}{m} = 2\pi f_c = \frac{2\pi n}{t_o} \tag{10}$$

and therefore from the above equation and equation (4)

$$\pi n = \frac{eBt_o}{2m} = \frac{eB^2 r_o}{mEo} \tag{11}$$

where t_o is the time taken by the resonant ion to reach a radius r_o.

The resonant ion path length is therefore given by

$$\lambda = \frac{eB^2 r_o^{\,2}}{mE_o} = 2r_o\ R \tag{12}$$

remembering that R is the resolution.

The sensitivity of the omegatron is defined by

$$S = \frac{Ic}{I_E\ P} \tag{13}$$

where Ic is the ion collector current, I_E is the electron beam current, and P is the pressure existing in the omegatron. The ion collector current in the omegatron for any given pressure and electron beam current is influenced by the ion path length given in equation (12). Any increase in the ionic path length will increase the chance that ions will be removed from their cyclic orbit and thus not be collected. Thus for maximum sensitivity the ion path length should be as short as possible. But from equation (12) decreasing the ion path length will also decrease the resolution and therefore, there must be a compromise between sensitivity and resolution to determine the values of r_o, B, and Eo in equation (12).

CHAPTER II

APPARATUS AND PROCEDURE

Apparatus.- The omegatron was mounted on a stainless steel ultra-high vacuum system with an internal volume of approximately 20 cubic feet. (See fig. 2.) All of the seals in the system were made with crushed metal "O" rings. The system was evacuated by a 10-inch diffusion pump in series with a 2-inch diffusion pump which was in turn backed by a 15 CFM roughing pump. A cold cap was installed in the 10-inch pump, and there was a liquid nitrogen cooled baffle between the 10-inch diffusion pump and the chamber. An ionization gage and a magnetron gage were used to measure the pressure. The chamber was baked at a temperature of 275° C to reduce the outgassing of the walls. The ultimate pressure in the chamber measured by the magnetron gage and corrected to account for the change in sensitivity of the magnetron gage (ref. 10) was about 2×10^{-11} torr. (All of the pressures quoted will be the equivalent nitrogen pressure.)

The omegatron was mounted on the side of the vacuum system and the magnet was mounted on a track so that it could be rolled away from the omegatron tube for baking the tube. (See fig. 2.)

A block diagram of the test apparatus is shown in figure 3. The bias voltages and the emission current for the omegatron were supplied by a commercial power supply. The radio frequency signal was supplied by a Hewlet Packard Model 650A RF osillator with a sweep drive mechanism.

The frequency meter was a Beckman Model 8370 and the data were recorded on a Electro Instrument Model 591 X-Y plotter. The ion currents from the omegatron were measured by a Applied Physics Model 31 vibrating reed electrometer. The connection between the preamplifier of the electrometer and the ion collector pin of the omegatron was made with solid coaxial cable utilizing sapphire disk insulators. The noise in the electrometer circuit was usually about 1×10^{-16} amperes.

Structural features of the omegatron.- Due to the necessity for baking the omegatron tube, it is constructed of materials capable of withstanding temperatures as high as 400° C. The sides of the ionization chamber, RF electrodes, electron beam focusing electrode, and electron collector are made of molybdenum (fig. 1). The ion collector is platinum and the ion collector shield is stainless steel. The filament and leads are tungsten as are the header leads.

The sides of the ionization chamber form the sides of a 2 cm square cube with holes in opposing sides to permit passage of the electron beam. The electron beam focusing electrode and the electron collector electrode are 0.005-inch molybdenum sheet, 12 mm square. The electron beam electrode has a 0.025-inch-diameter hole in the center to permit passage of the electron beam.

The basic difference between the simplified omegatron which is investigated in this paper and the original version proposed by Hipple, Sommer, and Thomas, is that the original version employed guard rings around the electric field to insure homogeneity in the electric field and the simplified version does not have the guard rings. McNarry (ref. 11) has shown that the electric field in the simplified omegatron is not homogenous.

Cleaning omegatron tube and magnet alinement.- The omegatron was prepared for the tests by a rigorous cleaning procedure. Since the cleanliness of the tube is essential for operation at very low pressures,, the procedure for cleaning the tube will be delineated here. After a pressure of about 2×10^{-10} torr had been attained in the vacuum system, the ionization chamber in the omegatron tube was heated white hot by an induction heater and held at this temperature for approximately 5 minutes. This induction heating was then stopped and the tube was baked with heating tapes to about 400° C for about 4 hours. At the end of the bake the tube was again heated by the induction heater for 5 minutes. The electron beam focus electrode was then biased positive about 500 volts with respect to the filament and the filament heated until there was a current of 25-30 microamps between the electron beam focus electrode and the filament. The electrical leads for operating the omegatron tube were then attached to the tube and the filament was biased negative about 150 volts with respect to the electron collector. The filament was again heated until there was a current of 20 microamps between the filament and electron collector.

This completed the cleaning procedure of the omegatron tube. In some cases, however, this cleaning procedure had to be repeated two or three times to properly clean the tube. If the tube was not cleaned properly the background current was found to vary with the RF frequency, and anomalous nitrogen and water peaks were observed in the mass spectrogram. After the tube had been cleaned, the magnet was rolled into place and aligned. The magnet was considered aligned when the emission current between the filament and electron collector was equal to the total electron current leaving the filament.

Total pressure measurement.- The total pressure in the chamber was measured by a commerical Bayard Alpert type gage (NRC 551) and a magnetron gage. The BA gage was used from 2×10^{-10} torr to 1×10^{-6} torr and the magnetron gage below 2×10^{-10} torr.

The BA gage was cleaned by baking for abour 4 hours at 300° C. A potential of +800 volts was then placed on the grid and the filament heated until about 125 milliamps were drawn from the filament to the grid. Fifteen minutes of this electron bombardment were sufficient to complete the cleaning of the BA gage. The magnetron gage was cleaned by simply baking at 300° C for 4 hours.

Gas inlet manifold.- To assure that only high purity gases enter the chamber a special gas inlet manifold was devised. The line from the pressure regulator on the test gas bottle to the gas inlet valve was evacuated with a roughing pump until the pressure was about 10 microns. The roughing pump was then valved off and the line backfilled with the test gas from the bottle until the pressure was about 5 psig. Using this procedure the amount of air left in the manifold was less than 1 percent of the test gas in the manifold. The test gas was admitted into the chamber through the gas inlet valve which was all metal and bakable. Although the valve was not designed to be a throttle valve, it worked very well as one. The leakage of gas into the chamber could be controlled so that the pressure could be controlled even in the 10^{-11} torr region if desired.

Test procedure.- The tests conducted were to determine the dependence of the ion current upon the trap voltage, electron collector voltage, and the RF voltage. If the values of trap voltage, electron collector voltage, and RF voltage to give the maximum sensitivity are not dependent upon the gas being analyzed nor upon the pressure of this gas, the omegatron could be used with greater facility as a partial pressure analyser.

These tests were conducted in the following manner. The vacuum chamber was evacuated and the omegatron tube cleaned as noted. When the pressure in the vacuum chamber was about 2×10^{-11} torr, the test gas was admitted into the chamber until the pressure desired was attained and then the test run was conducted. If the variation of ion current with trap voltage was desired the trap voltage would be changed manually and the ion current measured at each setting of the trap voltage. This procedure was repeated at various pressures. In a similiar manner the variation of ion current with electron collector voltage and RF voltage were determined at various pressures.

A separate series of tests were conducted to determine the sensitivity of the omegatron for helium, nitrogen, argon, and carbon dioxide. Again the test gas was admitted after a pressure of 2×10^{-11} torr had been attained in the vacuum chamber. For these tests, however, the frequency of the RF voltage was varied through a range sufficient to cause the various e/m ratios involved in the test run to become resonant. A test run while admitting several test gases simultaneously (air, argon, and carbon dioxide) is shown in figure 4. Of course in the tests to determine the sensitivity of the omegatron for the test gases only one test gas at a time was admitted into the chamber so that the partial pressure of test gas would be equal to the total pressure.

The residual pressure in the chamber before admitting the test gas was about 2×10^{-11} torr. If a test gas was admitted to raise the pressure in the chamber to 2×10^{-10} torr the residual gases accounted for about 10 percent of the total pressure and this percentage decreased as the pressure was raised. Thus the residual gases did not contribute significantly to the pressure for pressures above 2×10^{-10} torr. By admitting the test gas into the chamber and making such a scan of the e/m ratios the height of the test gas peak could be compared with the pressure and the sensitivity determined. If the rate at which the frequency was varied was slow enough the height of the test gas peak was equal to the ion current, Ic. A scan rate of about 2.5 minutes for the frequency span of $2\epsilon'$ (eq. (8)) was slow enough to insure that the peak height was equal to the ion current.

After the frequency had been varied to determine the peak heights at the first pressure, the gas inlet valve was opened further, a higher pressure was obtained, and the frequency again varied to determine the e/m ratios present. In this manner the sensitivity was determined over a pressure range from about 10^{-10} torr to 10^{-6} torr.

CHAPTER III

EXPERIMENTAL RESULTS

Effect of the cleanliness of the omegatron tube.- The cleanliness of the omegatron affected the value of trap voltage to give the maximum sensitivity. This effect can be seen in figure 5 which shows the variation of ion current with trap voltage before and after baking the omegatron tube. Before baking the tube, a trap voltage of 1.0 volt was required to obtain maximum sensitivity. After baking, however, the trap voltage for maximum sensitivity was only 0.6 volt. After cleaning the tube several times by baking and induction heating, the value of trap voltage for maximum sensitivity was found to remain constant even after further cleaning.

Variation of ion current with trap voltage.- The variation of ion current with trap voltage for argon for various pressures is shown in figure 6. The trap voltage to give the maximum sensitivity is 0.6 volt and is independent of pressure. Figure 7 shows the same variation except this figure is for nitrogen instead of argon. The maximum sensitivity for nitrogen occurs at a trap voltage of 0.5 volt. The difference in the ion current between these values of trap voltage is very slight, however, and the value of the trap voltage for maximum sensitivity is essentially the same for both gases. Similar tests conducted upon helium and carbon dioxide, but not presented here, showed that a trap voltage of 0.6 volt gave the maximum sensitivity for helium and carbon dioxide also. Thus the value of the trap voltage for maximum sensitivity is the same for helium, nitrogen, argon, and carbon dioxide, and is independent of the pressure.

Variation of ion current with electron collector voltage.- The variation of ion current with electron collector voltage for argon at various pressures is shown in figure 8. The value of electron collector voltage for maximum sensitivity for argon is 8 volts. Figure 9 shows the variation for nitrogen. The electron collector voltage for maximum sensitivity for nitrogen is 6 volts. Again the difference in ion current between these values of electron collector voltage is very slight, and the value of the electron collector voltage for maximum sensitivity is essentially the same for both gases. Tests with helium and carbon dioxide show that the value of electron collector voltage for maximum sensitivity was also 6 volts. Thus the value of the electron collector voltage for maximum sensitivity is the same for helium, nitrogen, argon, and carbon dioxide and is also independent of the pressure.

Figure 10 shows the variation of ion current with electron collector voltage for argon at various emission currents. The value of electron collector voltage for maximum sensitivity is 6 volts and is independent of the value of the emission current.

Variation of ion current with RF voltage for argon at various emission currents.- The variation of ion current with RF voltage for argon at various emission currents is shown in figure 11. Each curve represents the data taken at one emission current. The value of RF voltage for maximum sensitivity varies with the emission current. For emission currents from 0.25μA to 1μA the RF voltage for maximum sensitivity is almost constant at 2 volts rms. For emission currents greater than 1μA the value of RF voltage for maximum sensitivity increases as the emission current increases.

Figure 11 also shows that for a constant value of the RF voltage the ion current is not directly proportional to the emission current. If, for example, at an RF voltage of 1.5 volts rms the emission current is increased from 2μA to 3μA the ion current is actually decreased instead of increased. This occurance in the simple omegatron configuration has also been noted by Edwards (ref. 12), who suggested that it may be caused by a space charge in the ionization chamber of the omegatron tube. This space charge, Edwards suggests, is caused by the electron beam and the nonresonant ions around the electron beam. An ion produced in a 1μA electron beam must overcome a potential barrier about equal to the thermal energy of the ion to arrive at a point just 0.5 mm from the beam. Since this potential barrier increases with increasing beam current, this suggests that at the higher emission currents an appreciable portion of the ions produced in the electron beam are unable to escape from it.

Thus in the simple omegatron configuration the ion current is not directly proportional to the emission current for emission currents greater than 1μA. However, for those omegatron configurations employing guard rings to insure homogeneity in the electric field, the ion current is directly proportional to the emission current for values of the emission currents as great as 20μA. (See refs. 13 and 14). A clue to the reason for this difference between the two omegatron configurations is given by McNarry (ref. 10), who shows that the electric field in the simple omegatron configuration is not homogeneous throughout the space inside the RF electrodes. In fact in the simple omegatron the electric field in the vicinity of the electron beam is much less than it would be if the electric field were homogeneous. Thus in the omegatron configuration employing guard rings the electric field in the vicinity of the electron beam is much greater than in the corresponding location in the simple omegatron configuration. In the simple omegatron configuration, therefore, the electric field in the vicinity of the electron bean is not strong enough to extract the ions from the vicinity of the electron beam because of the space charge caused by the electron beam and the nonresonant ions.

Sensitivity.- The sensitivity of the omegatron was found to depend upon the RF voltage, trap voltage, and electron collector voltage as well as the parameters indicated in equation (13). Therefore, the sensitivity will be defined for constant values of RF voltage, trap voltage, and electron collector voltage. The values of trap voltage and electron collector voltage were chosen to give maximum sensitivity, but as indicated in equation (12) the RF voltage is a compromise between sensitivity and resolution. For partial pressure analysis the sensitivity should be as high as possible while the resolution should be adequate to separate completely the argon peak from carbon dioxide peak. An RF voltage of 1.5 volts rms was chosen to satisfy these conditions.

The sensitivity of the omegatron for helium, nitrogen, argon, and carbon dioxide is determined from the data presented in figures 12, 13, 14, and 15. In each figure the ion current from the test gas is plotted versus the pressure in the vacuum system for an emission current of 1 microamp. The line shown through the data was computed by the method of least squares. If the sensitivity were independent of pressure the ion current would be directly proportional to pressure and the slope of the line in figures 12, 13, 14, and 15 would be one. Since the slope of these lines is not one the sensitivity is dependent upon the pressure.

There is only a slight sensitivity dependence upon the pressure for helium, nitrogen, and argon. This is seen from the fact that the slope of the ion current versus pressure line in figures 12, 13, and 14 is only slightly greater than one. The slope of the lines is listed under "b" in table I. There are reasons to expect the slope of this ion current versus pressure line might be slighly greater than one. At low pressures the residual gases in the vacuum system constitute a larger percentage of the pressure than at higher pressures, so that at low pressures the partial pressure of the test gas is not equal to the total pressure. This effect of the residual gases would cause an apparent low sensitivity at low pressures and therefore, the slope of the line would be greater than one.

The slope of the line showing the variation of ion current with pressure for carbon dioxide is shown in figure 15 and is 0.924. This apperent increase in the sensitivity at low pressures is an anomaly, and a reason for it is lacking.

The variation of ion current with pressure is given by the expression

$$\log_{10} I_c = a + b \log_{10} P \tag{14}$$

Values for a and b for the lines shown in figures 12, 13, 14, and 15 are shown in table I. The pressures in figures 12 through 15 are in equivalent nitrogen pressures. These pressures must be corrected to account for the change in ionization gage sensitivity for each test gas. The true pressure can then be used to calculate the sensitivities from equation (13). Using the values of the ionization gage sensitivity for helium, nitrogen, and argon from Dushman and Young (ref. 15) and the value for carbon dioxide from Wagenek and Johnson (ref. 16), the true pressures were determined for the test gases for an equivalent nitrogen pressure of 10^{-9} torr. Using the value of the ion currents at 10^{-9} torr from figures 12 through 15 and the true pressures, the sensitivities were calculated at a pressure of 10^{-9} torr equivalent nitrogen pressure. These sensitivities are listed in table II.

Resolution.- As already noted, the resolution of the omegatron could be improved by reducing the RF voltage. For an RF voltage of 1.5 volts rms the theoretical resolution was computed from equation (8) for various gases. The resolution could also be measured because the $2\epsilon'$ in equation (8) is the width of the base of the resonant ion peaks. The theoretical and measured resolution are listed in table III for various gases. Figure 16 shows that the resolution is sufficient to separate the argon peak (mass 40) from the carbon dioxide peak (mass 44).

Tests were conducted on a separate omegatron tube of the same configuration. The sensitivity of the second tube for the test gases agreed with the data from the first tube within 10 percent.

CHAPTER IV

CONCLUSIONS

The value of trap voltage, electron collector voltage, and RF voltage for maximum sensitivity is independent of the pressure and gas for helium, nitrogen, argon, and carbon dioxide. The omegatron can therefore be used at various pressures and still be a quantitative analyzer. The ion current is not proportional to the emission current for emission currents above 1μA. Therefore increasing the emission current in order to increase the ion current from small peaks is not helpful in the simple omegatron configuration.

The omegatron analyzer tube itself is well suited for analysis of the residual gases in an ultra-high vacuum chamber. The tube is easily cleaned and after proper cleaning does not contribute a self spectrum to the mass spectrogram obtained. The partial pressures as measured by the omegatron show, therefore, the gases in the vacuum chamber and not gas being evolved from the analyzer tube itself. The sensitivity of the omegatron is essentially constant from one analyzer tube to the next and does not seem to vary as the tube ages. The ratio of the sensitivity of the omegatron for various gases is about the same as the ratio of the ionization gage sensitivities. The ion collection efficiency is slightly higher for the omegatron than for the ionization gage. The sensitivity is slightly dependent upon the pressure for helium, argon, and nitrogen. For carbon dioxide the sensitivity apparently increases at low pressures.

A disadvantage of the omegatron is that the ion currents are very small, and the equipment and technique necessary to measure them are sophisticated. Vibrating reed type electrometers with solid coaxial cable from the ion collector pin on the omegatron tube to the preamplifier are required for measuring the lowest peak heights. The electrical connections between the ion collector pin and the electrometer must be kept clean and any vibration of the omegatron tube itself can cause large background noise to show up in the electrometer.

Since the ion currents involved are so small the mass range must be scanned very slowly. A scan from mass 12 to mass 44 takes about 30 minutes. This is a decided drawback if the pressure inside the vacuum system is changing. Of course, the scan rate can be accelerated with a consequent decrease in sensitivity and resolution. The measured resolution is about one-third of the theoretical resolution but is still adequate to separate mass 40 from mass 44.

The lowest partial pressure that can be measured depends upon the electrometer. With the instrumentation used here the lowest partial pressure measurable was 2×10^{-11} torr.

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TABLE I

Constants for equation 14

GAS	a	b
Helium	10.29	1.02
Nitrogen	10.20	1.014
Argon	10.47	1.034
Carbon Dioxide	8.44	.924

TABLE II

Omegatron sensitivity compared with ionization gauge sensitivity

GAS	IONIZATION GAUGE SENSITIVITY ($torr^{-1}$)	OMEGATRON SENSITIVITY ($torr^{-1}$)
Helium	1.6	2.0
Nitrogen	10.0	11.5
Argon	11.9	17.5
Carbon Dioxide	13.7	25.0

TABLE III

Cyclotron frequency and resolution for various masses

M/e	f_c (KCPS)	Theoretical Resolution	Measured Resolution
4	1542	280	86
16	385	70	17.5
20	308	56	20.5
28	219	40	14.6
32	191.5	35	11.3
40	153	28	10
44	139	25	8.7

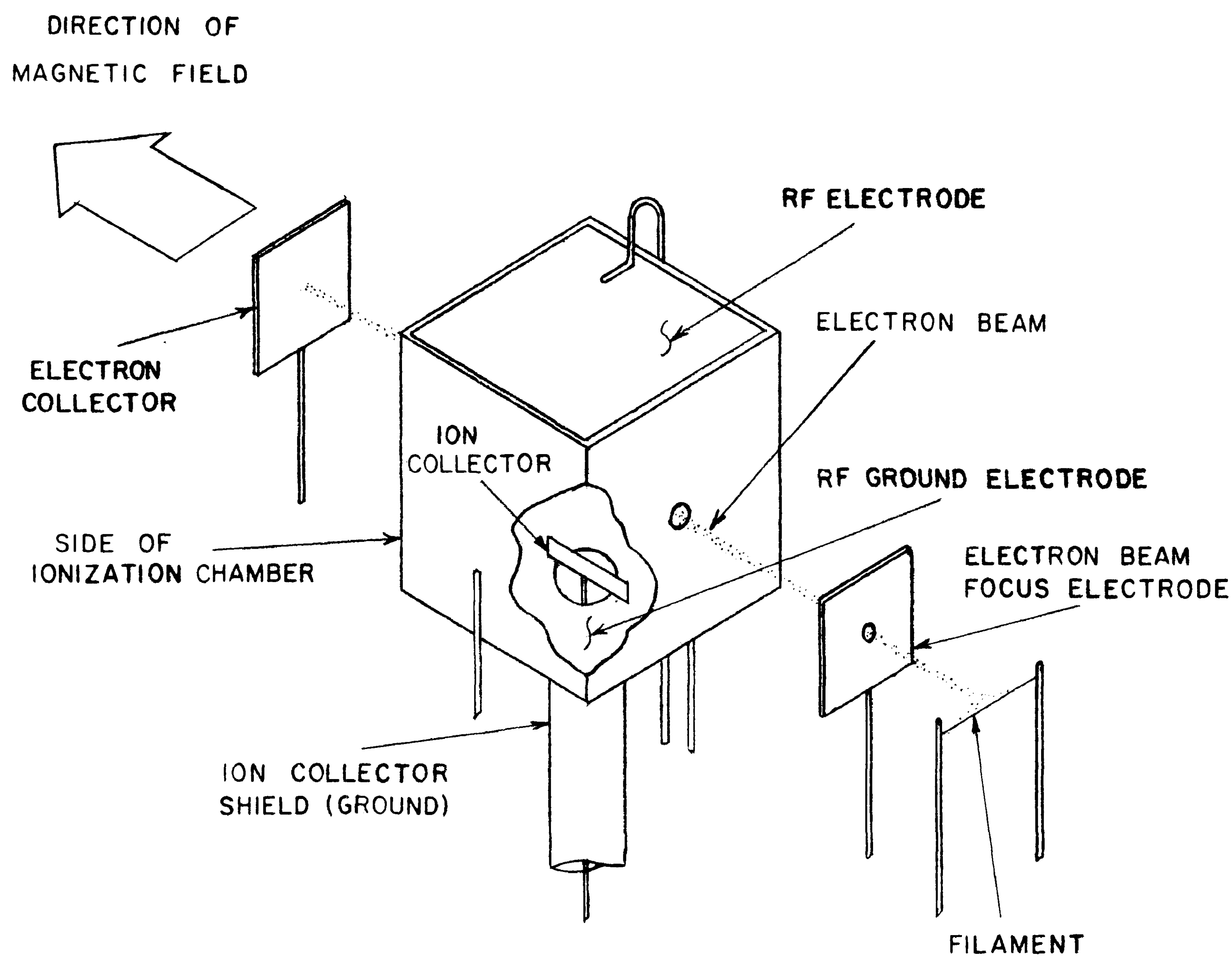

Figure 1.- Physical arrangement of electrodes inside omegatron tube.

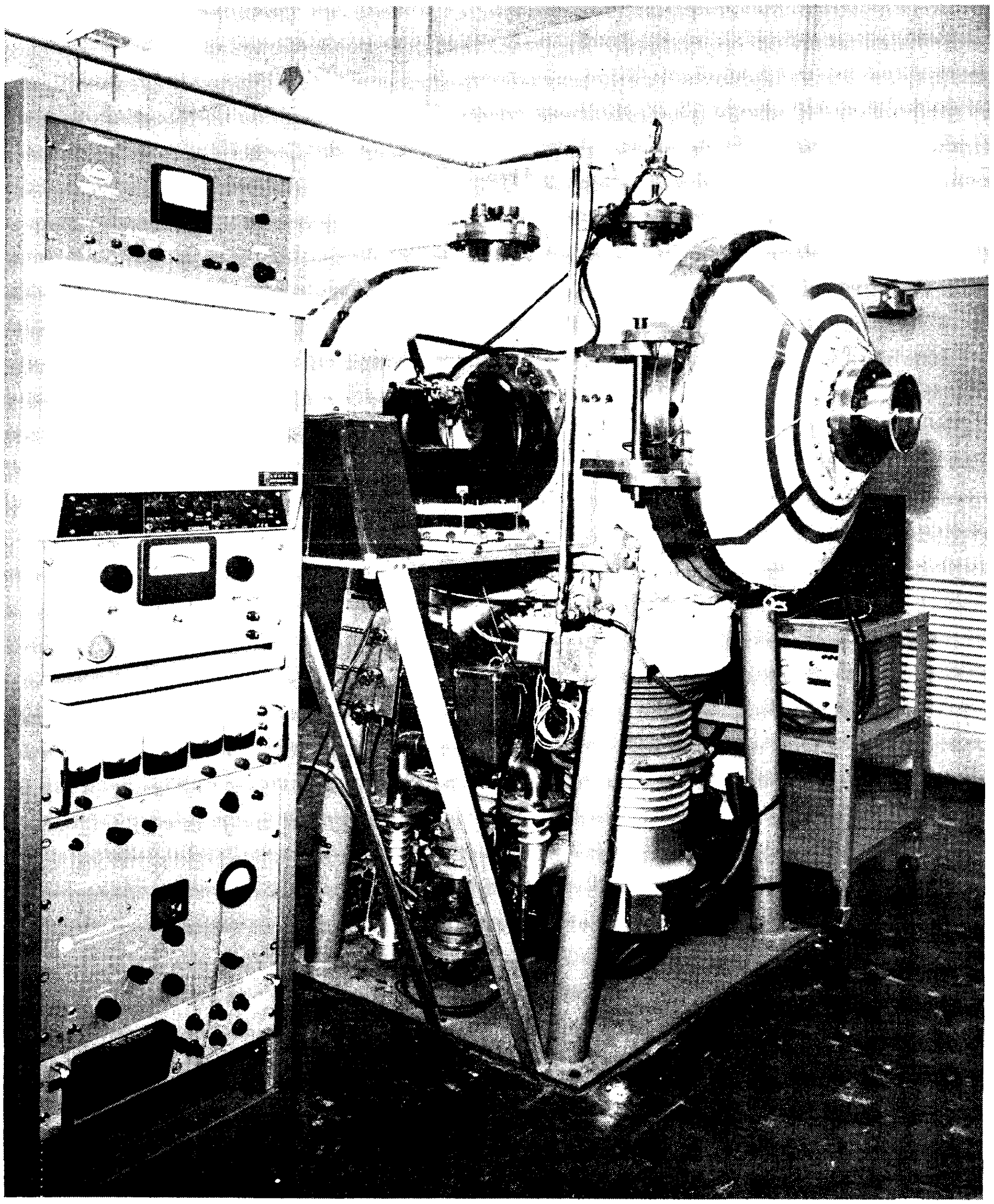

Figure 2.- Vacuum chamber showing location of omegatron tube.

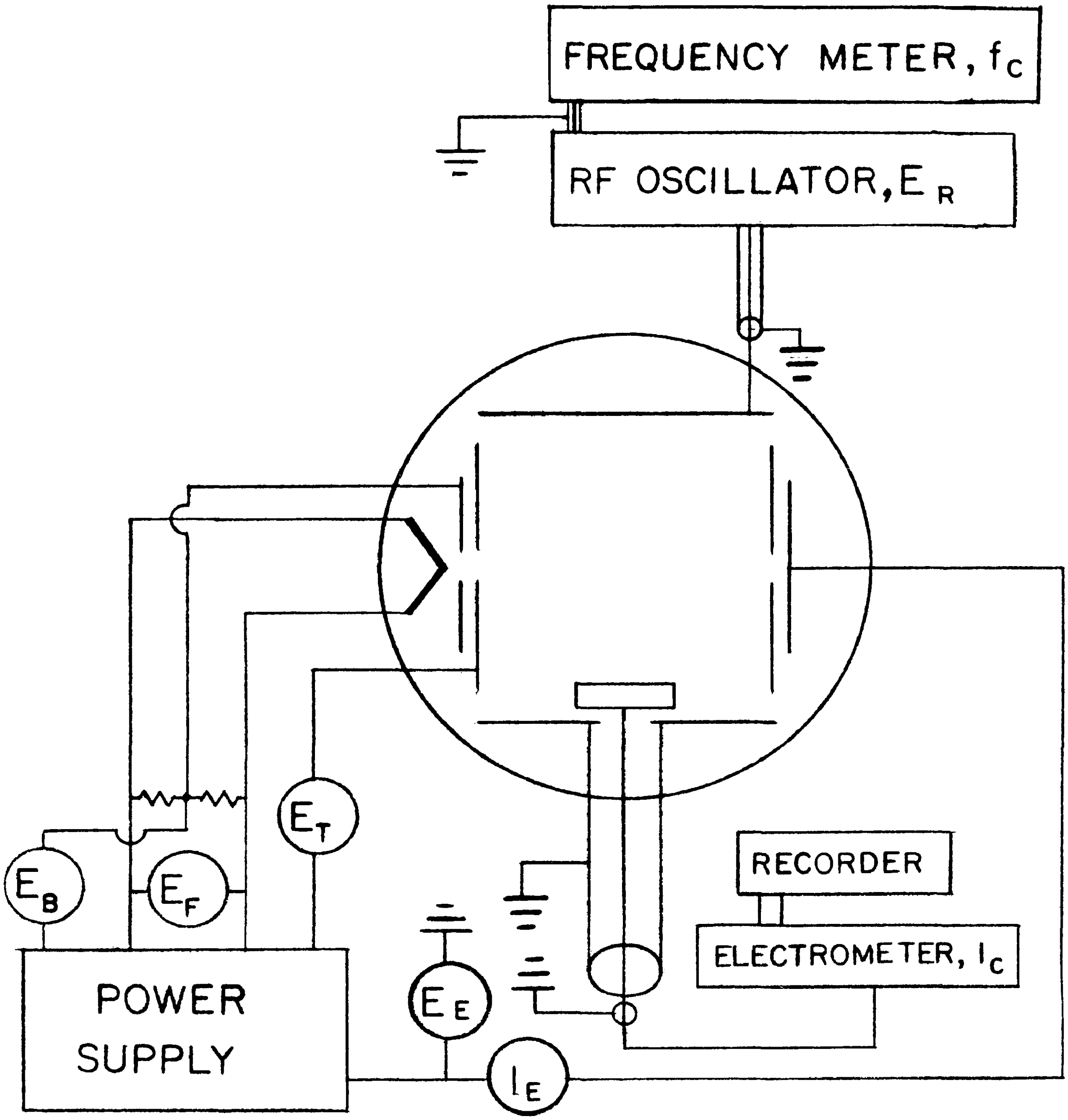

Figure 3.- Block diagram for omegatron partial pressure analyzer.

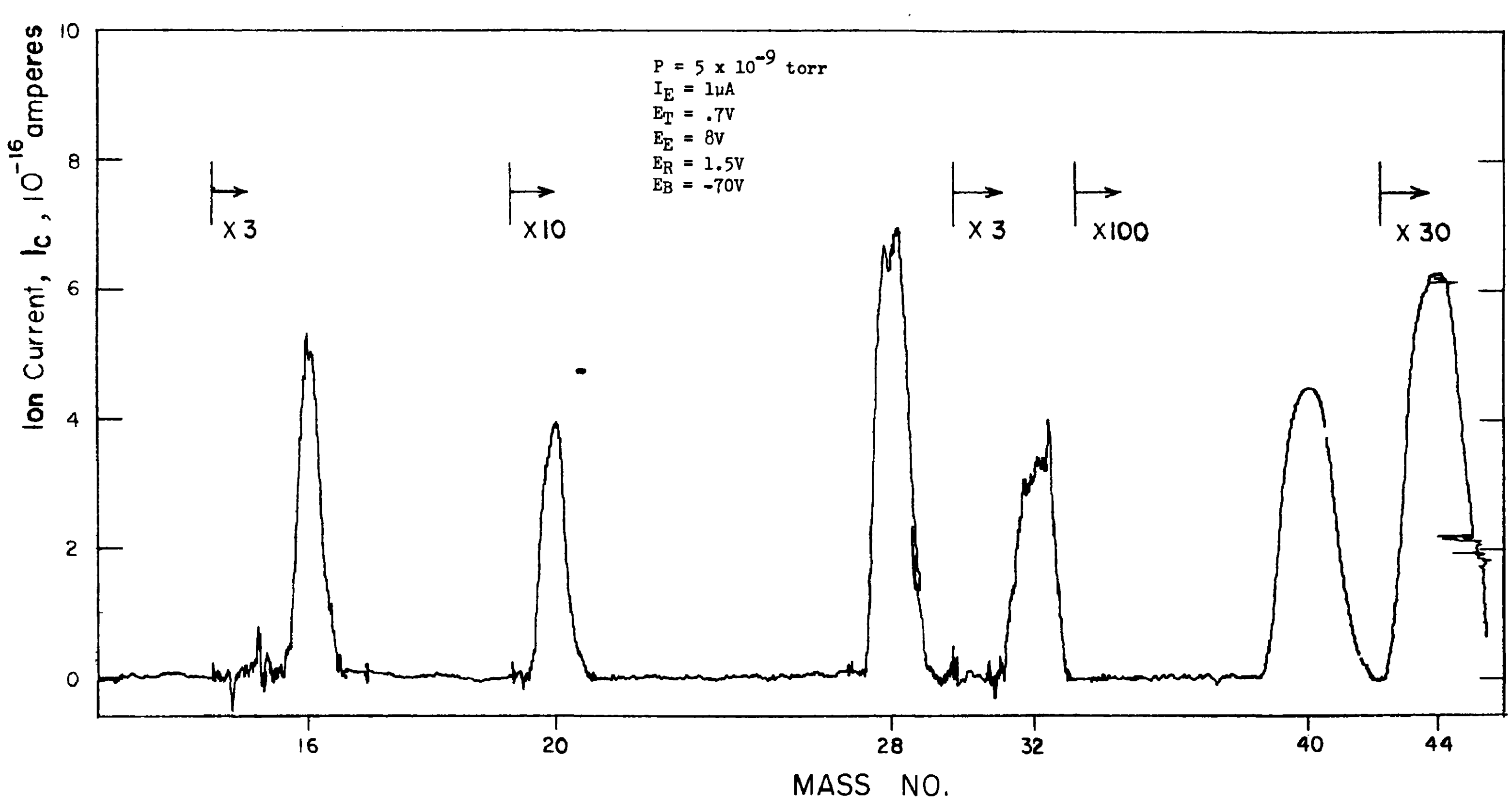

Figure 4.- Mass spectrogram while inletting air, argon, and carbon dioxide.

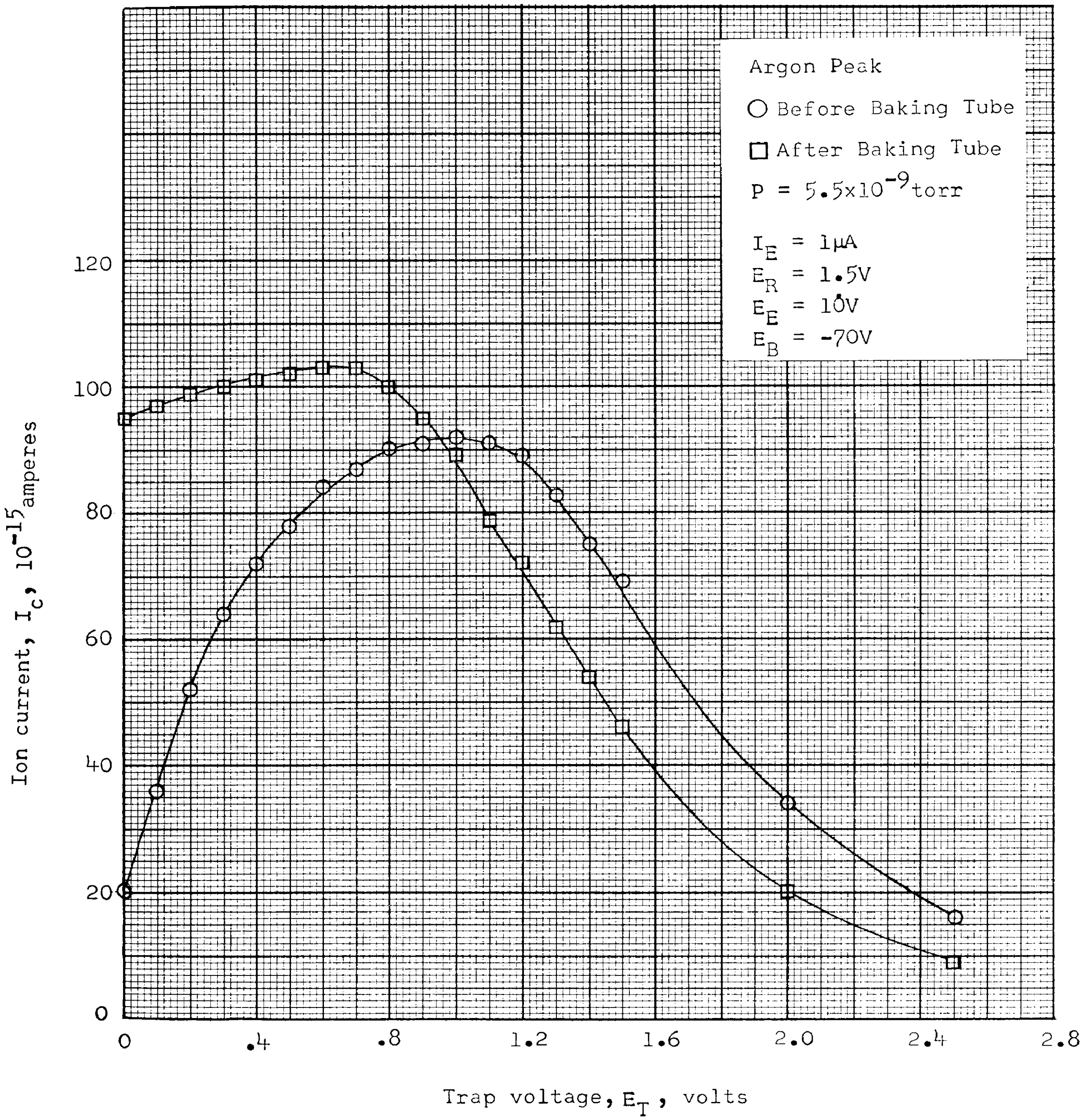

Figure 5.- Variation of ion current with trap voltage before and after baking tube.

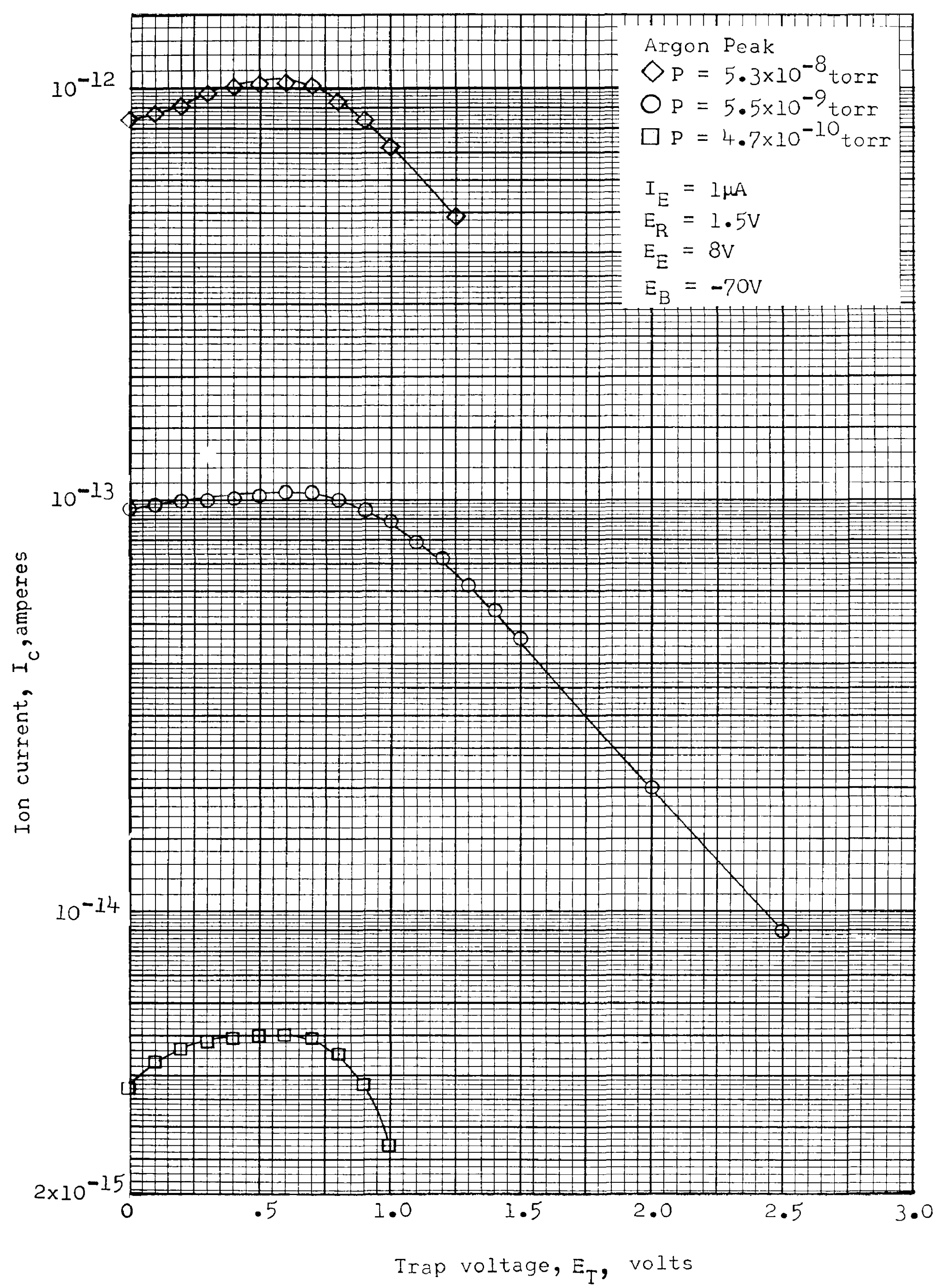

Figure 6.- Variation of ion current with trap voltage for argon at various pressures.

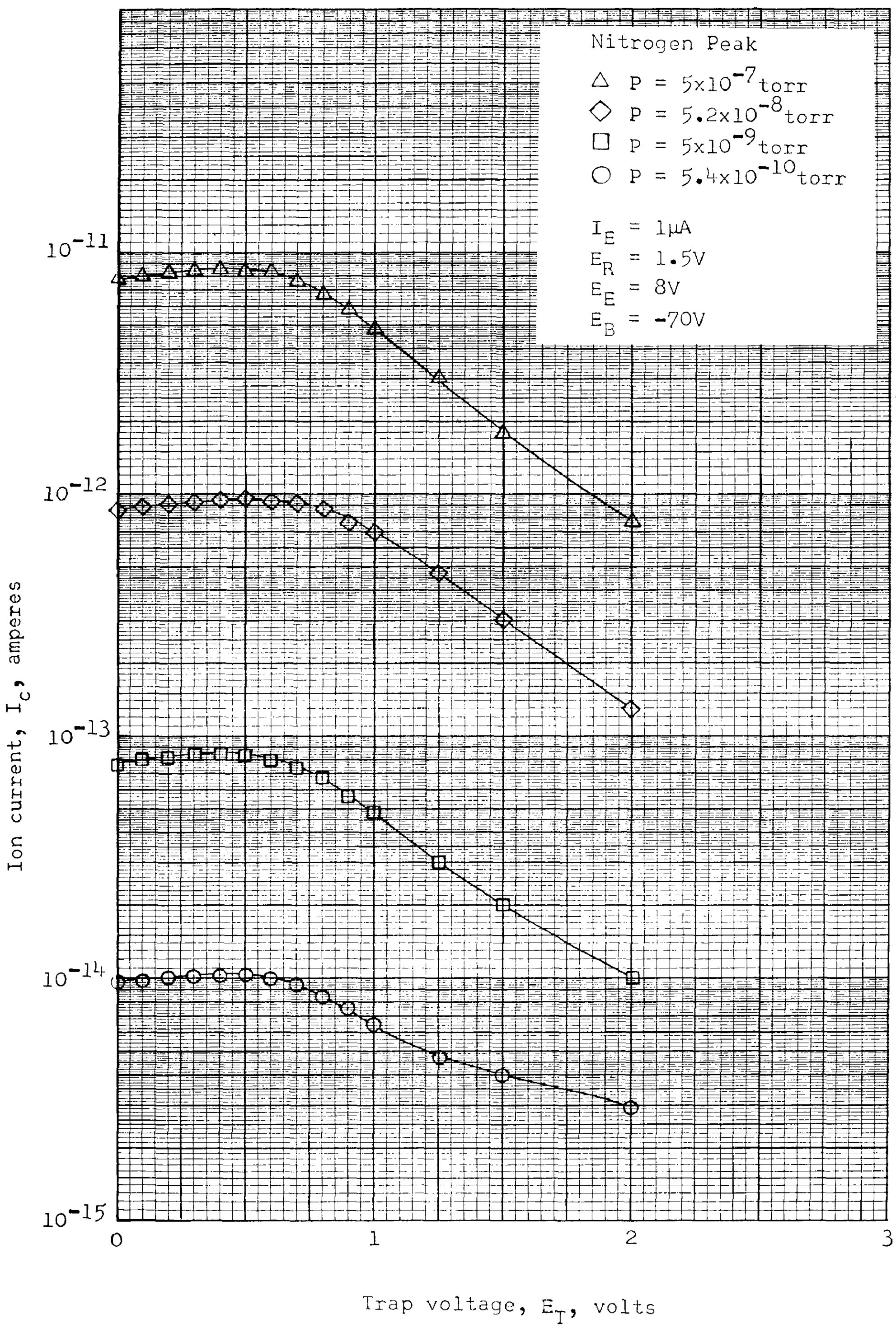

Figure 7.- Variation of ion current with trap voltage for nitrogen at various pressures.

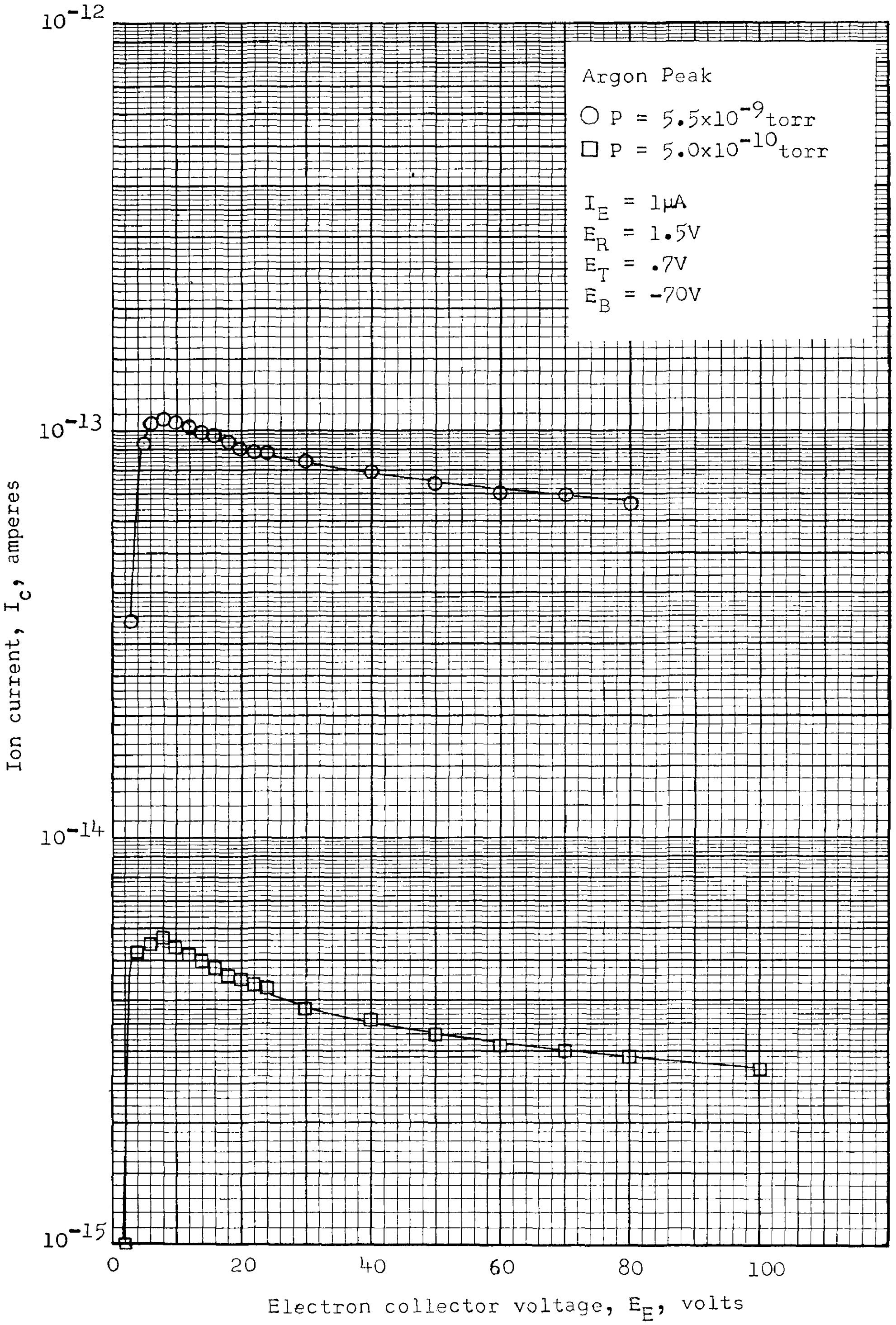

Figure 8.- Variation of ion current with electron collector voltage for argon at various pressures.

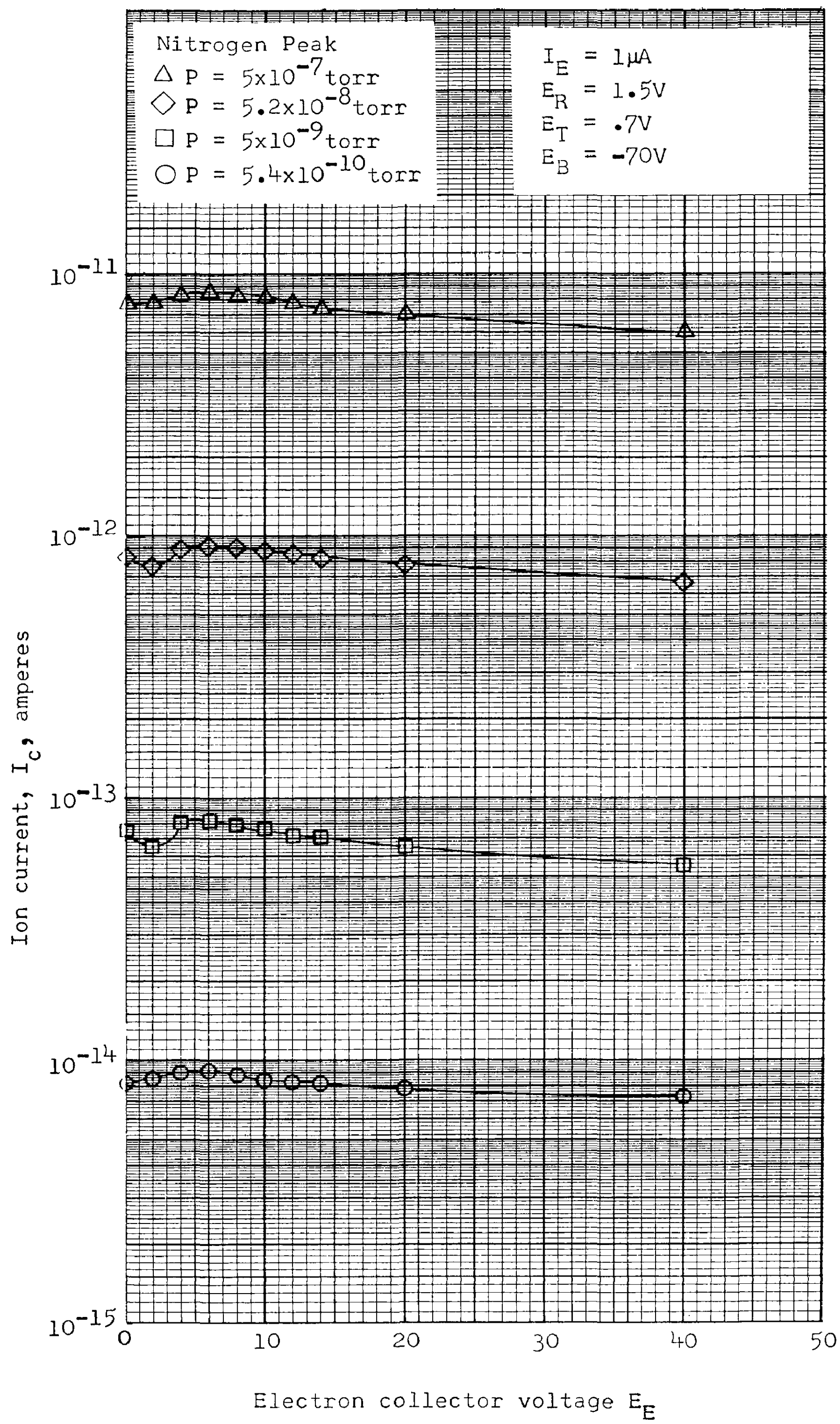

Figure 9.- Variation of ion current with electron collector voltage for nitrogen at various pressures.

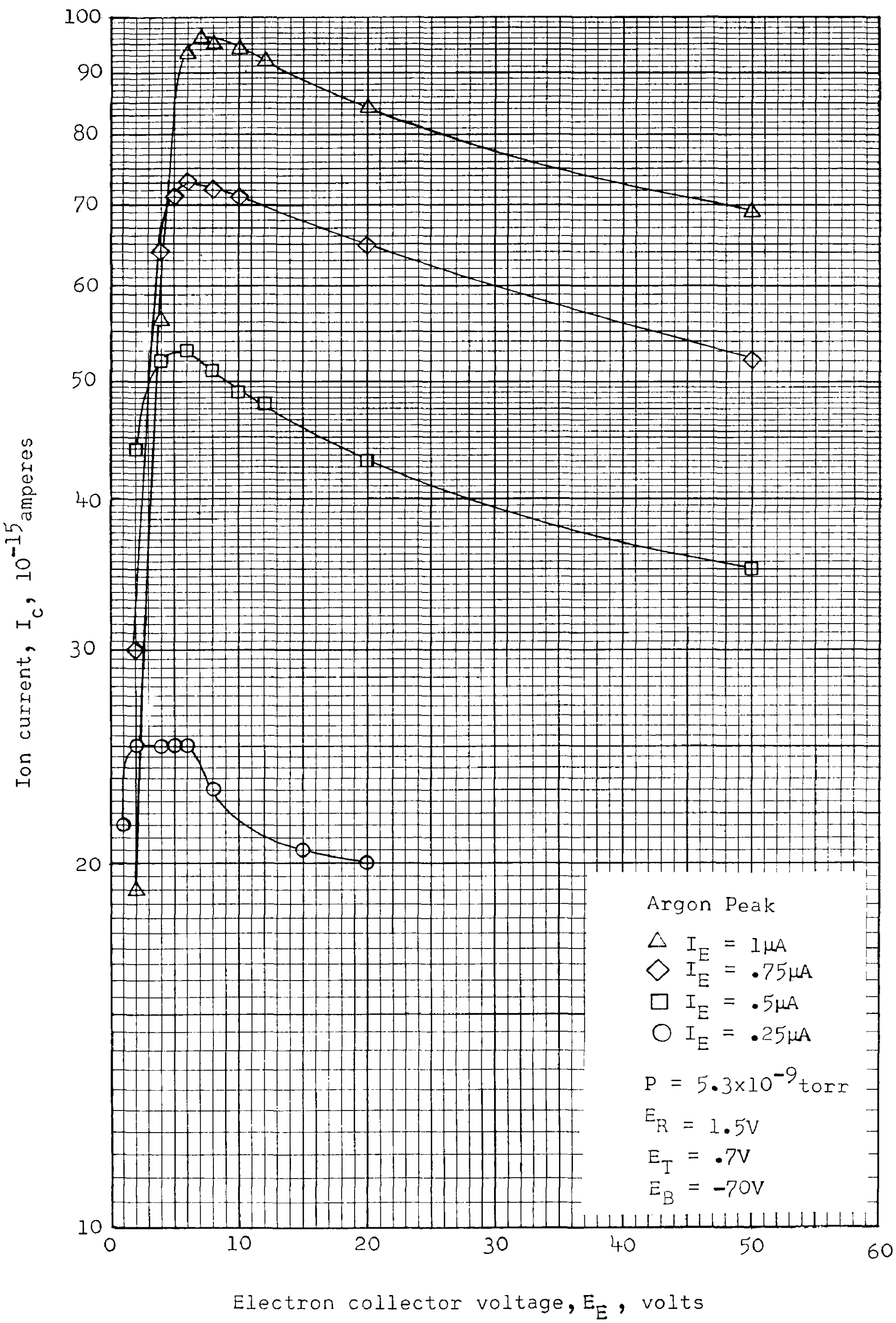

Figure 10.- Variation of ion current with electron collector voltage for argon at various emmission currents.

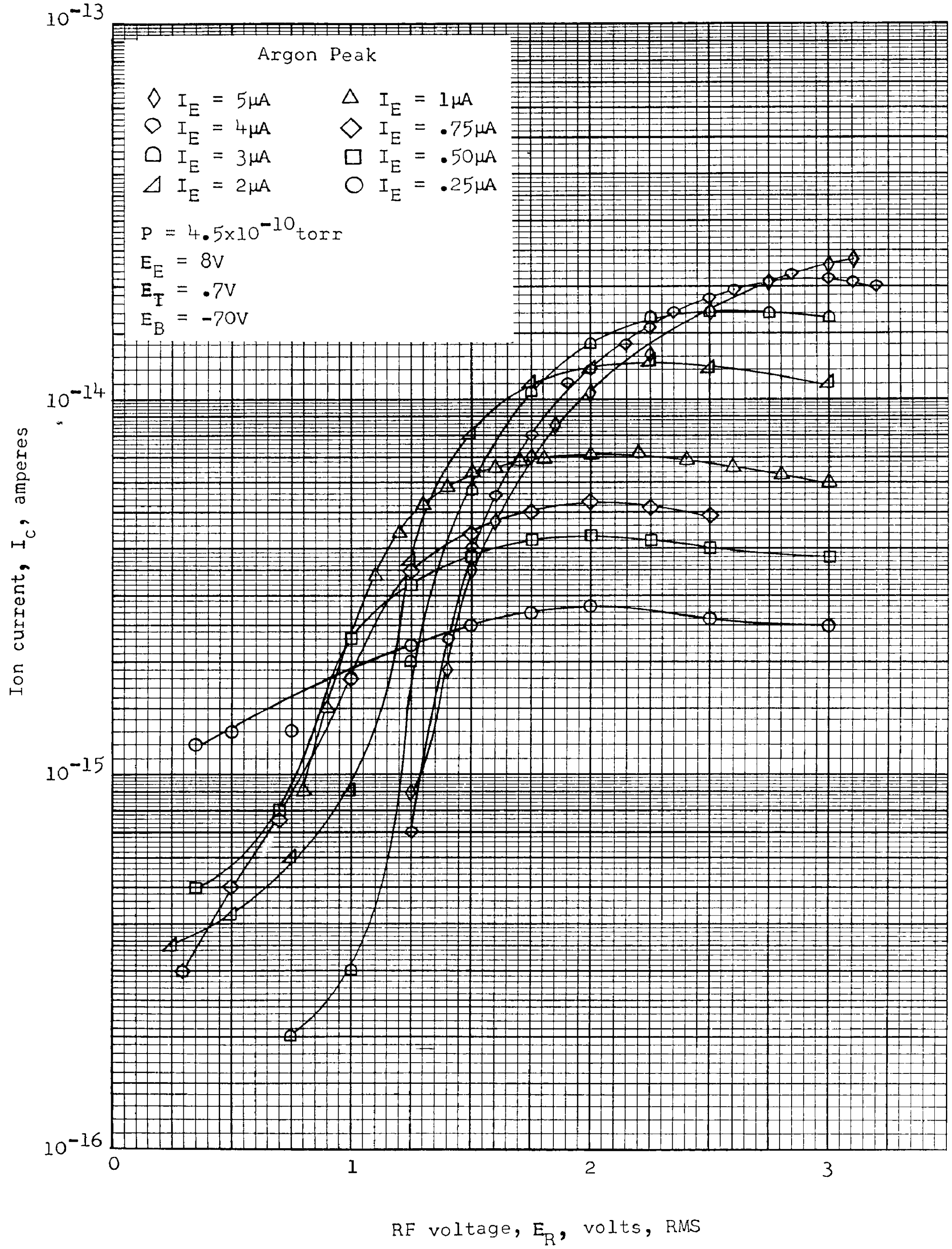

Figure 11.- Variation of ion current with RF voltage for argon at various emission currents.

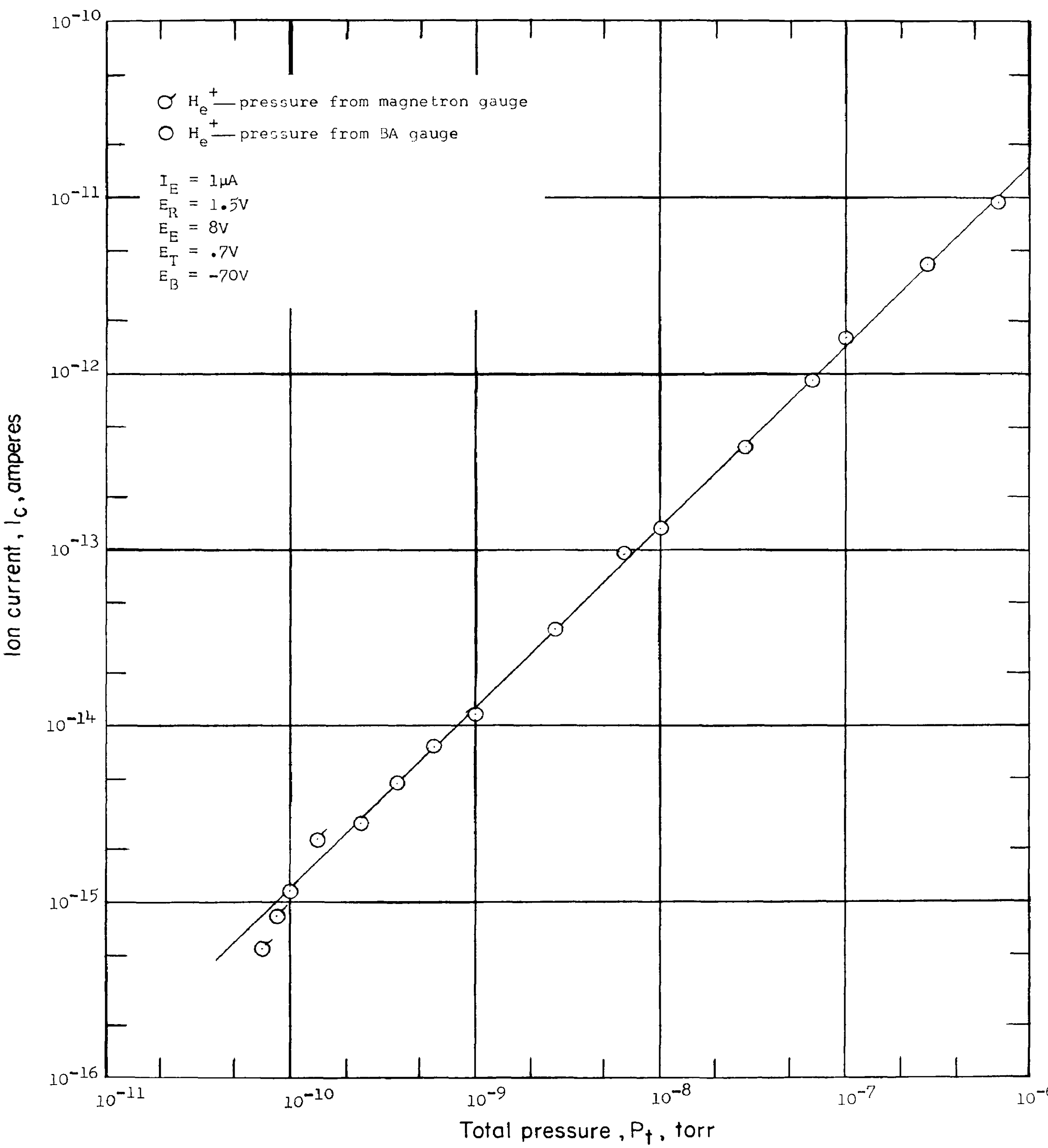

Figure 12.- Variation of ion current with pressure for helium.

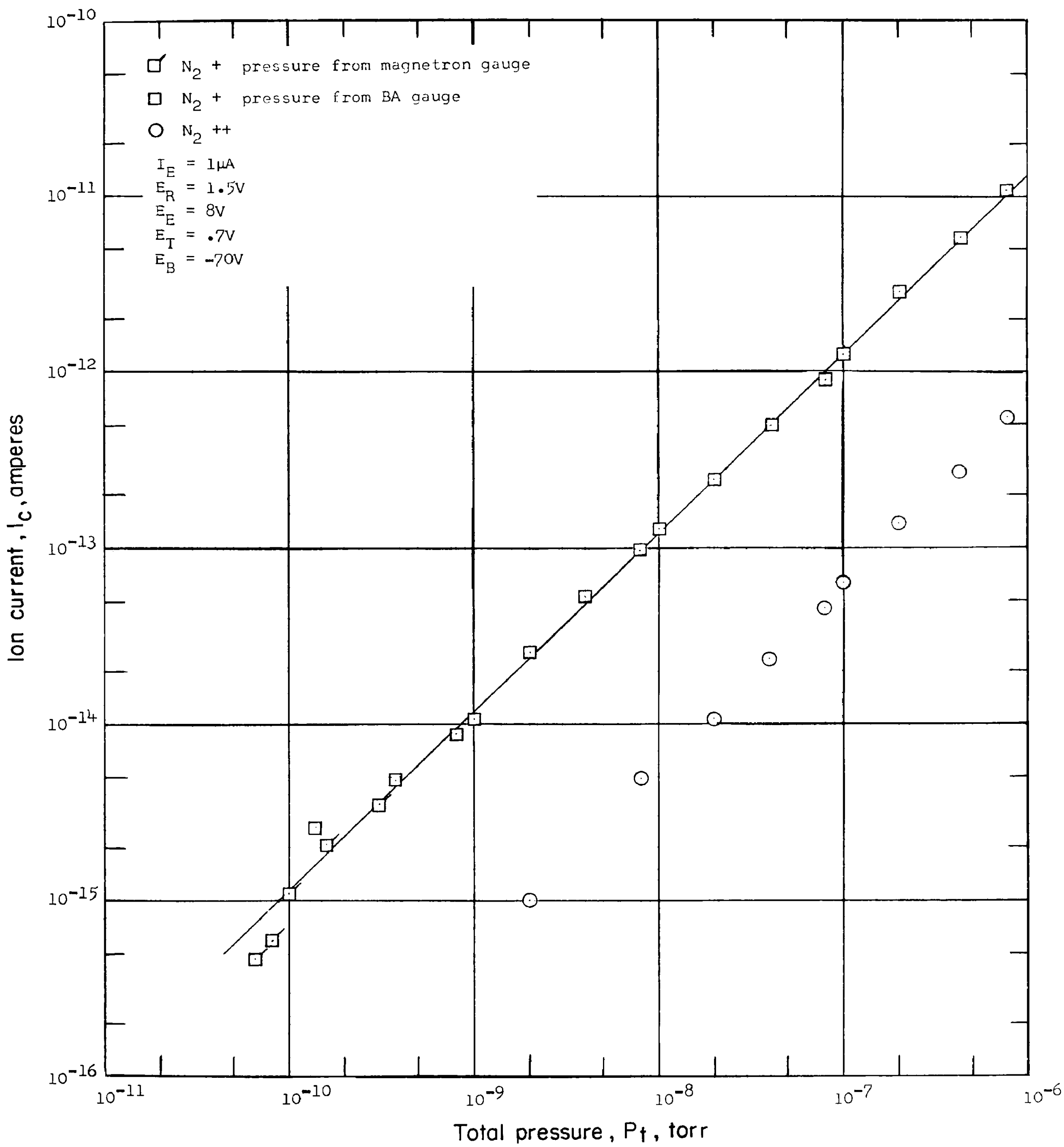

Figure 13.- Variation of ion current with pressure for nitrogen.

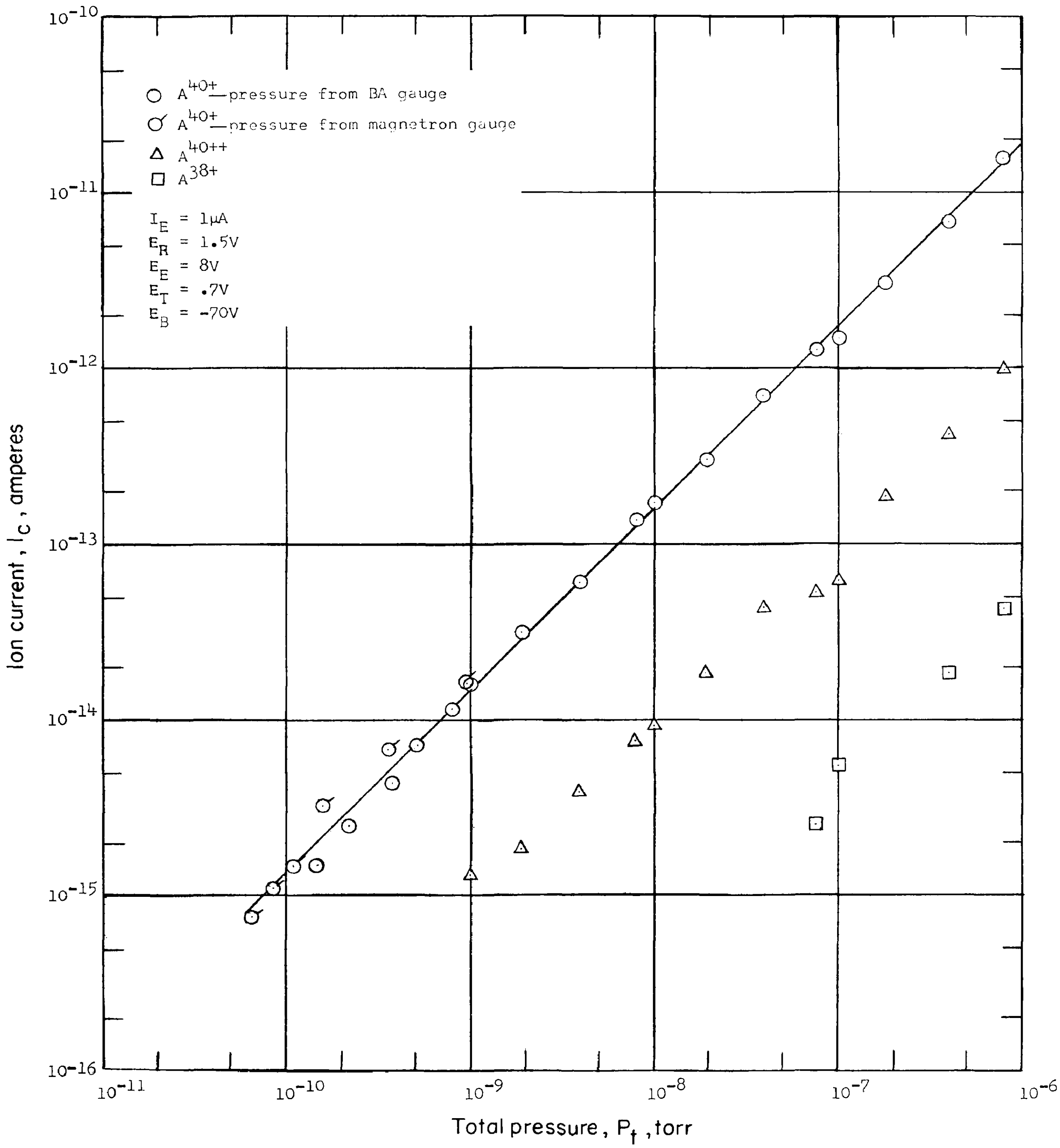

Figure 14.- Variation of ion current with pressure for argon.

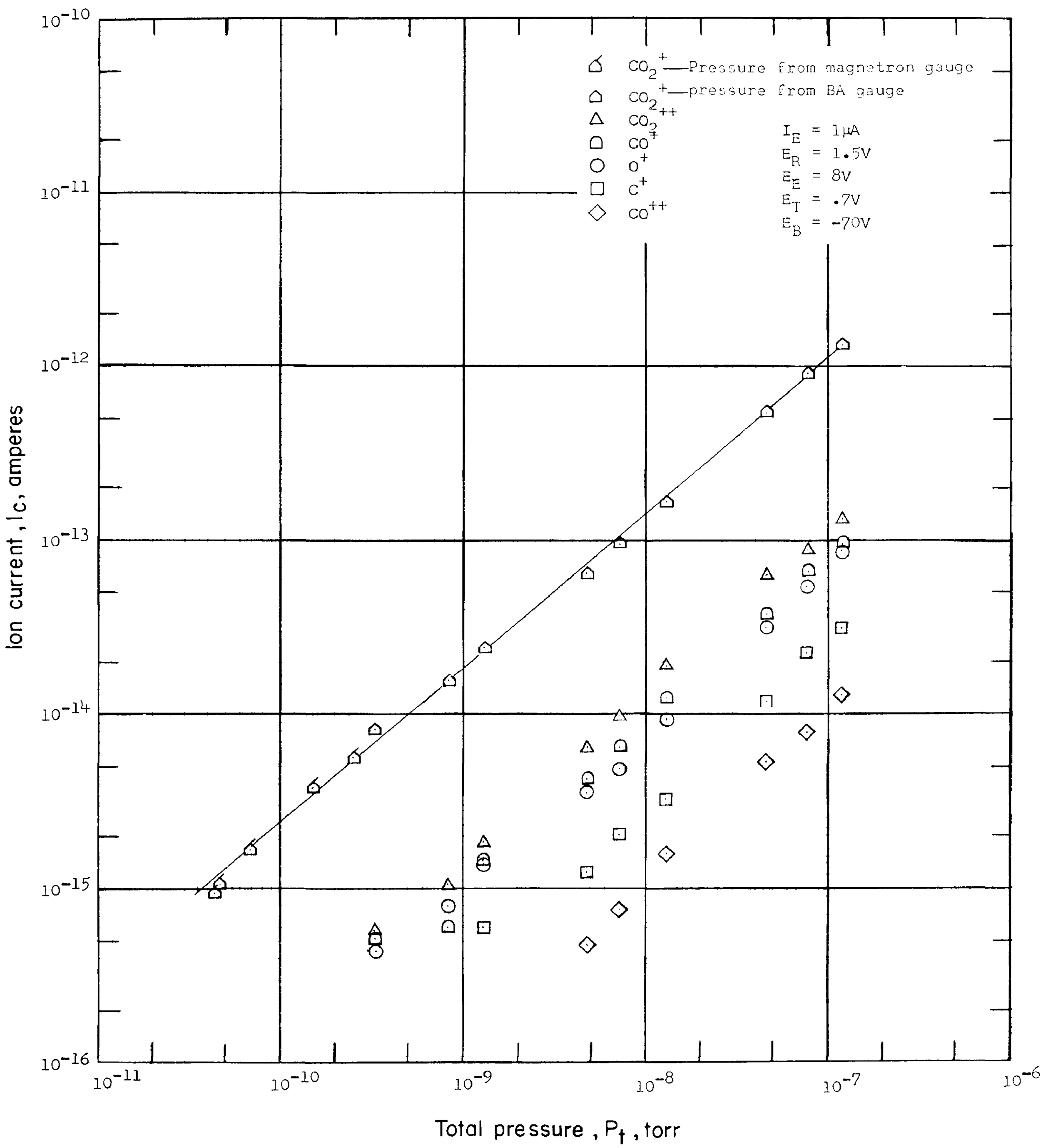

Figure 15.- Variation of ion current with pressure for carbon dioxide.

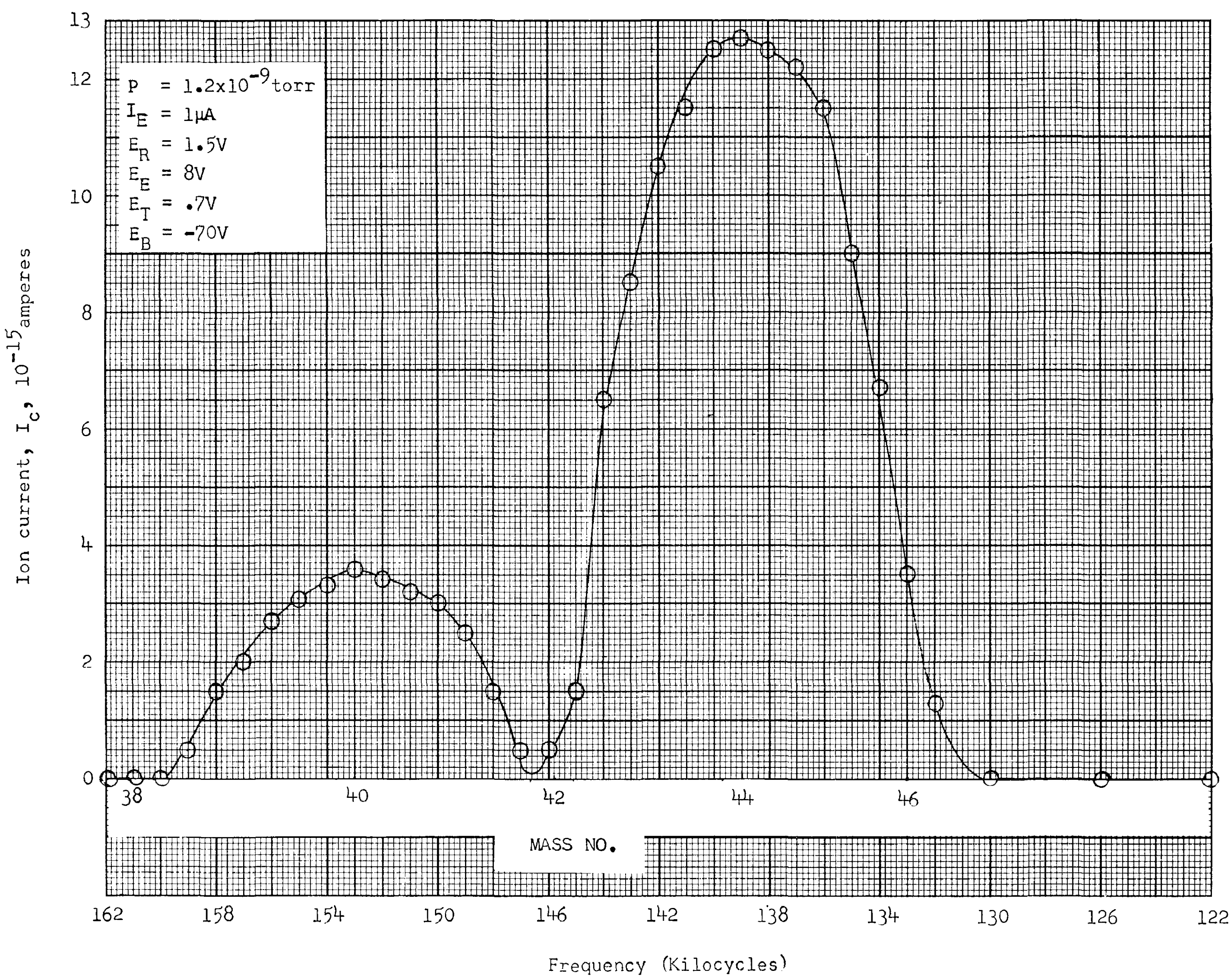

Figure 16.- Mass spectrogram while inletting argon and carbon dioxide.