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VARIATIONS IN GAGE CONSTANT AS A FUNCTION OF EMISSION CURRENT IN AN UNSHIELDED OPEN-END GRID BAYARD-ALPERT IONIZATION GAGE

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VARIATIONS IN GAGE CONSTANT AS A FUNCTION OF EMISSION CURRENT IN AN UNSHIELDED OPEN-END GRID BAYARD-ALPERT IONIZATION GAGE[1]

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SUMMARY

A detailed laboratory study has revealed a gage-constant—emission-current anomaly in the 1- to 10-milliampere emission-current range in an open-end grid Bayard-Alpert ionization gage. This study was performed for the pressure range from 6×10^{-2} to 1×10^{-5} N/m^2 on an orifice-conductance calibration system with a computed pressure measurement uncertainty of ±5.5 percent.

Experimental data are presented which show variations in gage constant as high as 18 percent for low pressures (pressures less than 10^{-2} N/m^2) and for high emission currents generally used by most investigators. In addition, this anomaly was found to be independent of pressure and, therefore, does not affect the gage output linearity. However, a knowledge of this behavior is important when calibration procedures with the McLeod gage are considered, because these procedures require changing the gage tube emission current.

INTRODUCTION

For the measurement of pressures below 10^{-1} N/m^2, some form of the ionization gage is generally used. Many gages of this type are available to the investigator, including both the hot filament and cold cathode types. The gage most often used in the pressure range from 10^{-1} to 10^{-6} N/m^2 is the hot filament ionization gage of the Bayard-Alpert type.

In most tests, the effect of the environmental pressure in space simulation facilities on the experimental accuracy is of a first order. A detailed study, therefore, of the Bayard-Alpert type of gage to determine its reliability and accuracy is required.

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[1]After completion of this investigation, it was found that Kazuo Ishikawa found a similar anomaly in a closed grid Bayard-Alpert gage. Portions of his work were published in the Japanese Journal of Applied Physics, vol. 4, no. 6, June 1965, pp. 461-465.

In the past, ionization gage studies have been limited in the accuracy of gage calibration techniques and the inability to maintain an accurately known constant pressure. The use of the standard commercial ionization gage control units also limits the accuracy of such studies. A calibration system was needed which required no assumptions concerning the operation of the gage tube. In order to meet this need, a gas-flow-rate—orifice-conductance system (ref. 1) was chosen which could establish known pressures in the gage calibration chamber to within ±5.5 percent of measurement over a range from 1×10^{-7} to 6.65×10^{-2} N/m^2 and hold these pressures constant to ±1 percent of measurement. A monitored laboratory ionization gage control unit was used to make current and voltage measurements with a total measurement uncertainty of ±3 percent.

It is the purpose of this report to document an emission-current—ion-current anomaly for emission currents greater than 3 milliamperes and pressures less than 10^{-2} N/m^2 unreported for this Bayard-Alpert type of gage. This anomaly appears as a change of gage constant as a function of emission current. The significance of this anomaly is brought forth in the calibration procedure in which the McLeod gage is used. This technique allows the use of a McLeod gage as a calibration standard by reducing the emission current in the ionization gage to avoid the well-known saturation effect (ref. 2) at high pressure and high emission current. The emission current is then raised at low pressure to regain sensitivity and to avoid low-emission-current low-pressure effects (ref. 3). The use of this technique is questioned, however, since the data in this report indicate calibration errors as high as 18 percent.

SYMBOLS

i^+	ion collector current, amperes
i^-	emission current, amperes
k_1	ionization gage constant, (newtons/meter^2)$^{-1}$
$\bar{l}$	average distance of travel of electron from filament to grid, centimeters
n	number density, molecules/centimeter^3
p	pressure, newtons/meter^2 (133 N/m^2 = 1 torr)
Q	gas flow rate, newton-liters/meter^2-second
S	speed, liters/second
σ	ionization cross section, centimeters^2

DESCRIPTION OF APPARATUS

The apparatus consisted of a gas-flow-rate—orifice-conductance vacuum gage calibration system (ref. 1) for establishing known pressure levels, a precision ionization gage control unit for gage tube operation, and an open-end grid Bayard-Alpert ionization gage.

The vacuum gage calibration system (figs. 1, 2, and 3) utilizes 500-liter/second ion pumps in conjunction with titanium sublimation and liquid nitrogen cryopanels to produce an ultimate chamber pressure less than 3×10^{-9} N/m^2. This system generates known pressures in the calibration chamber by utilizing a constant pressure gas flowmeter for generating and measuring a gas flow rate Q into the calibration chamber while pumping the gas from the chamber through a known conductance orifice at a known speed S. The pressure in the calibration chamber is then calculated by the relation:

$$p = Q/S \tag{1}$$

The assumption is made that this gas flow rate Q is much larger than that of all other gas sources and that the speed S at the orifice is much smaller than the pump speed. The calibration range of this system extends from 1×10^{-7} to 6.65×10^{-2} N/m^2.

A precision ionization gage control unit (fig. 4) was utilized for operating the ionization gage tube. This control unit is completely metered for simultaneous monitoring of all gage tube voltages and currents.

The ionization gage tube (figs. 5 and 6) consists of a hot filament, grid, and ion collector. Ionization of gas molecules is accomplished by using the hot filament as an electron source. The electrons, accelerated to the positive grid, ionize gas molecules which collect at the negative ion collector and produce a positive ion current. This ion current should be proportional to the gas pressure in a given gas at a constant temperature.

MEASUREMENT UNCERTAINTY

A measurement uncertainty analysis was made on the ability to produce a known constant pressure and the voltage and current measurements of the precision laboratory ionization gage control unit. Since the measurement of the flow rate Q is determined from volumetric cylinder displacement, elapsed time, and pressure measurements (ref. 1), evaluation of the uncertainties of these parameters by using the technique of differential calculus (ref. 4) yields a measurement uncertainty in Q of ± 3 percent. A similar analysis of the pumping orifice speed S, whose measurement uncertainties arise from uncertainties in orifice diameter, thickness measurement, and variations in the vacuum pump speed,

yields an uncertainty of ±2.5 percent. This analysis yields a total uncertainty in the chamber pressure of ±5.5 percent.

The precision ionization gage control unit was used to produce the required voltages and currents for the proper operation of the gage tube. The uncertainties of these voltage and current measurements are given in the following table:

Measurement	Range	Uncertainty, percent
Grid voltage, V	0 to 300	±1 (full scale)
Collector voltage, V	0 to 150	±1 (full scale)
Emission current, mA	0.01 to 100	±1.5 (of reading)
Ion current, A	10^{-13} to 10^{-3}	±1.5 (of reading)

For gage tube operation at saturated grid and collector potentials, the total uncertainty in determining the gage constant $k_1 = \frac{i^+}{i^- p}$ at any given pressure, emission current, and ion current was computed to be ±8.5 percent.

EXPERIMENTAL STUDIES

The Bayard-Alpert type ionization gage was combined with the precision gage controller and the digital voltmeter, as illustrated in figure 6. The gage tube was connected to the gage calibration system by using tubulation having a calculated conductance of 7.8 liters/sec. If the gage pumping speed is assumed to be proportional to emission current with a value of 0.1 liter/sec (ref. 5) at 10 milliamperes emission current, then the pressure in the gage tube is 0.987 that of the known pressure in the calibration system. Similarly, at 1 milliampere emission the pressure in the gage tube would be 0.998 that of the known pressure in the calibration system. Thus if the gage constant is determined at 1 milliampere emission current, use of this gage constant at 10 milliamperes should indicate a gage pressure 1.3 percent below the known pressure level.

The calibration system was evacuated to a pressure of less than 10^{-8} N/m^2. All data in this report were taken with nitrogen gas at known pressures at least two decades above the ultimate pressure of the system. The following voltages were applied to the gage tube:

Collector to filament	-30 volts
Grid to filament	150 volts

The filament was biased at 30 volts to obtain a grounded collector. The gage tube was outgassed by using both high-temperature bakeout and resistance outgassing

until an indicated background current of approximately 2×10^{-11} ampere was obtained in its operational mode. This value of the background current, which is the known value for this ionization gage due to photon ejected electrons from the collector (ref. 6), indicated that the tube elements are free from adsorbed gases. The thermal transpiration effect (ref. 7) was computed to determine measurement error due to gas temperature in the gage. The temperature of the gage envelope, adjacent to the filament, was measured at emission currents of 1 and 10 milliamperes. If the gas is in equilibrium with the wall temperature, the measured 6° K change in envelope temperature produces a difference between the indicated gage pressure and the known calibration system pressure of approximately 1 percent.

In order to determine the characteristics of the gage, the validity of the known ionization gage equation (ref. 8)

$$i^{+} = \sigma n \bar{l} i^{-} \tag{2}$$

must be determined. Use of the ideal gas law at room temperature (300° K) yields

$$n = 2.42 \times 10^{14} p$$

Therefore

$$i^{+} = 2.42 \times 10^{14} \sigma \bar{l} i^{-} p \tag{3}$$

The gage constant is defined as

$$k_1 = \frac{i^{+}}{i^{-} p} \tag{4}$$

Combining equations (3) and (4) gives

$$k_1 = \frac{i^{+}}{i^{-} p} = 2.42 \times 10^{14} \sigma \bar{l} \tag{5}$$

In order to test the validity of equation (5), it is necessary to assure that

$$i^{+} = k_2 i^{-} \tag{6}$$

for a constant pressure, where

$$k_2 = k_1 p$$

and, in addition

$$i^+ = k_3 p \tag{7}$$

where

$$k_3 = k_1 i^-$$

Equations (6) and (7) may hold separately but for equation (5) to be valid both must hold in the range of emission current and pressure in question.

Equation (6) was tested by plotting a curve (fig. 7) of ion current as a function of emission current for a number of constant pressures. This curve shows that equation (6) holds for emission currents less than 3 milliamperes and pressures less than 6.2×10^{-2} N/m^2. This figure illustrates the expected nonlinearity (ref. 2) at high pressures ($p > 10^{-2}$ N/m^2) and high emission currents ($i^- > 3$ mA). However, a nonlinearity at pressures less than 10^{-2} N/m^2 and emission currents greater than 3 milliamperes is also demonstrated. These data establish a gage-constant—emission current anomaly for open-end Bayard-Alpert ionization gages and show the deviation from linearity to be as high as 18 percent at 10 milliamperes emission current. The observed nonlinearity is large compared with the scatter in the experimental data as well as the maximum possible measurement uncertainty of ± 4 percent since the value of the constant pressure is not considered.

Since the deviation from linearity for a given emission current is constant for pressures below 6.2×10^{-2} N/m^2, equation (7) is valid in this range. If the same data are plotted in the form of ion collector current as a function of pressure for several emission currents above 3 milliamperes (fig. 8), equation (7) is shown to be valid in this emission current range. The net effect of this anomaly is a change in gage constant as a function of emission current. The data from figure 7 are presented in the form of gage constant as a function of emission current in figure 9 to display this effect. The average gage constant for an emission current of 1 milliampere is 8.4×10^{-2} (N/m^2)$^{-1}$, whereas, for an emission current of 10 milliamperes, it is 6.9×10^{-2} (N/m^2)$^{-1}$. These values show an error of 18 percent, which evolves when emission currents are changed in this pressure range. These tests were repeated for three other gages and the data agreed within the instrumentation accuracy. The effects demonstrated by the data in figure 7 are summarized in the following table:

Pressures, N/m^2	Emission range, mA	Equations valid
3.9×10^{-5} to 6.2×10^{-2}	0.05 to 3	(4), (6), and (7)
3.9×10^{-5} to 6.2×10^{-2}	3 to 10	(7)
$>6.2 \times 10^{-2}$	3 to 10	None

The importance of this anomaly is emphasized by the fact that gages are calibrated at high pressures ($p > 10^{-2}$ N/m^2) to allow the use of a McLeod gage as the calibration standard and at low emission currents ($i^- < 1$ mA) to avoid the well-known saturation effect. It is then customary to raise the emission current to a larger value ($i^- \approx 10$ mA) to regain sensitivity and to avoid low-pressure—low-emission-current effects (ref. 3). The data in this paper indicate that this calibration procedure can introduce large errors and, therefore, should be avoided whenever possible.

Inasmuch as the emission current and pressure in equation (5) are measurable, a change in gage constant as a function of emission current must be caused by a change in ion production or collection. Since the ion current is a linear function of pressure (fig. 8) over the range of pressures investigated, the collection of ions as a cause of the anomaly is doubtful. The production of ions appears to be the cause. The right-hand portion of equation (5) ($k_1 = 2.42 \times 10^{14}\sigma\bar{l}$) indicates that the anomaly is caused by a change in path length, a change in ionization cross section, or by both. If only the ions produced inside the grid contribute to the ion current, and if the electron energy is 150 volts, the potential in the grid structure would have to drop to 50 volts (ref. 9) in order to account for this effect. Since a drop in voltage of this magnitude is unlikely, a path length change appears to be the major cause.

A plot (fig. 10) of gage constant as a function of grid to filament voltage indicates that for voltages greater than 150 volts the error caused by emission-current change decreases. This trend strongly indicates a space charge buildup inside the grid structure which could affect the cross section or path length at high emission currents and thus cause the anomaly. The data of figure 10 also indicate that operation of the gage at higher filament to grid voltages would minimize the anomaly. However, the disadvantages of this operation are increased X-ray background current (ref. 6) and increased outgassing produced by higher grid power dissipation.

Inasmuch as these problems could seriously disturb the measurements, it is recommended that the gage be calibrated and operated at a fixed emission current by using 150-volt grid to filament voltage and thereby avoiding this anomaly. Since the ion collector current is saturated above 20 volts for all pressures and emission currents, the use of 30 volts for the collector is recommended.

CONCLUSIONS

The data in this report describing the operational characteristics of the open-end Bayard-Alpert ionization gage have led to the following conclusions:

1. When the gage is operated at a constant emission current, the ion current as a function of pressure is linear.

2. The ion-current—emission-current characteristic curve is nonlinear (18 percent) at emission currents greater than 3 milliamperes and at pressures less than 10^{-2} N/m^2. This nonlinearity results in a change in gage constant as a function of emission current.

3. A knowledge of the gage-constant—emission-current anomaly is important when calibration procedures with the McLeod gage are considered, because these procedures require changing the gage tube emission current.

4. These data are offered to describe this anomaly and should not be construed as correction data. Corrections can only be determined by proper calibration of the gage under consideration.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 29, 1966,
125-24-03-03-23.

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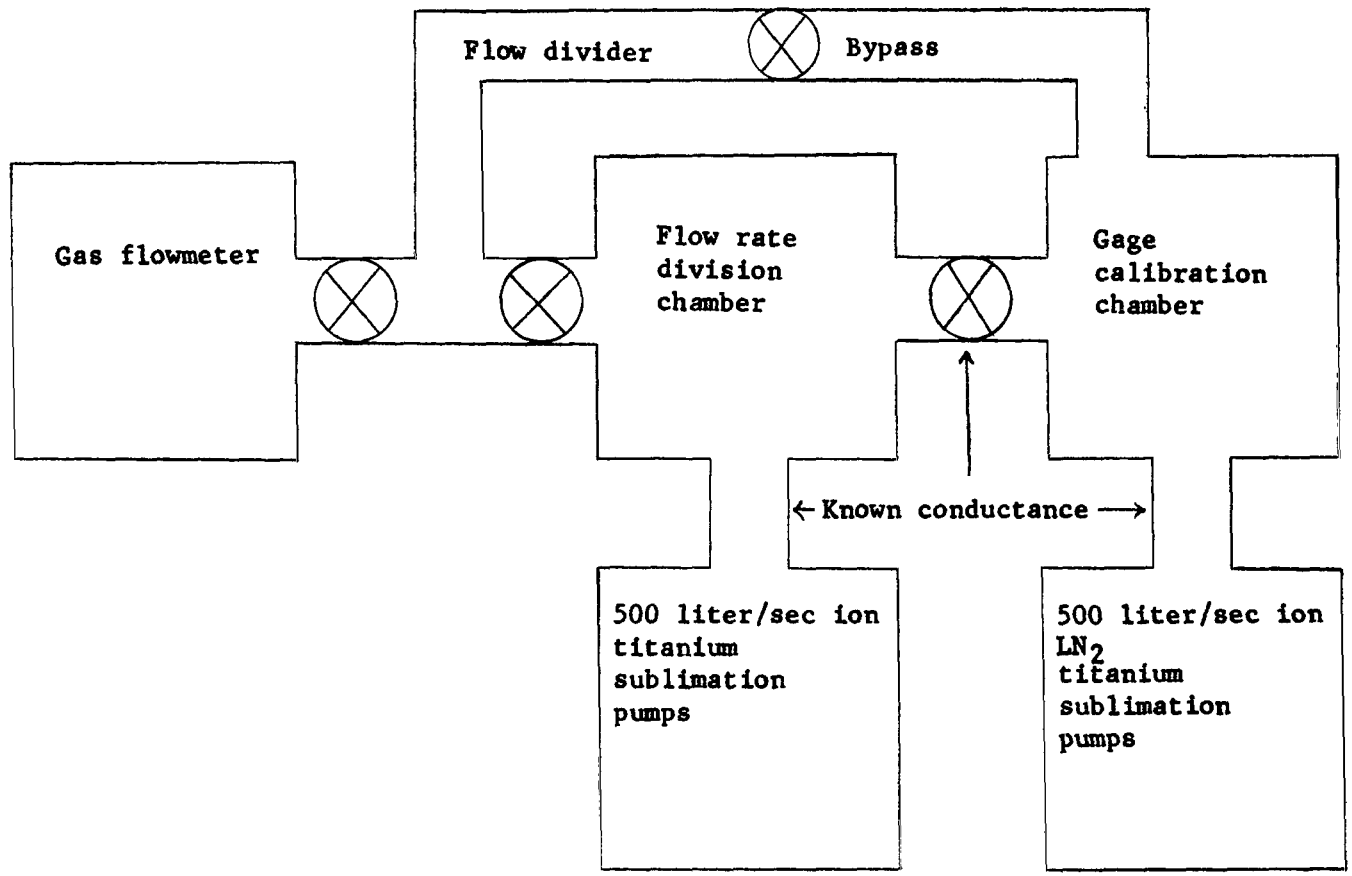
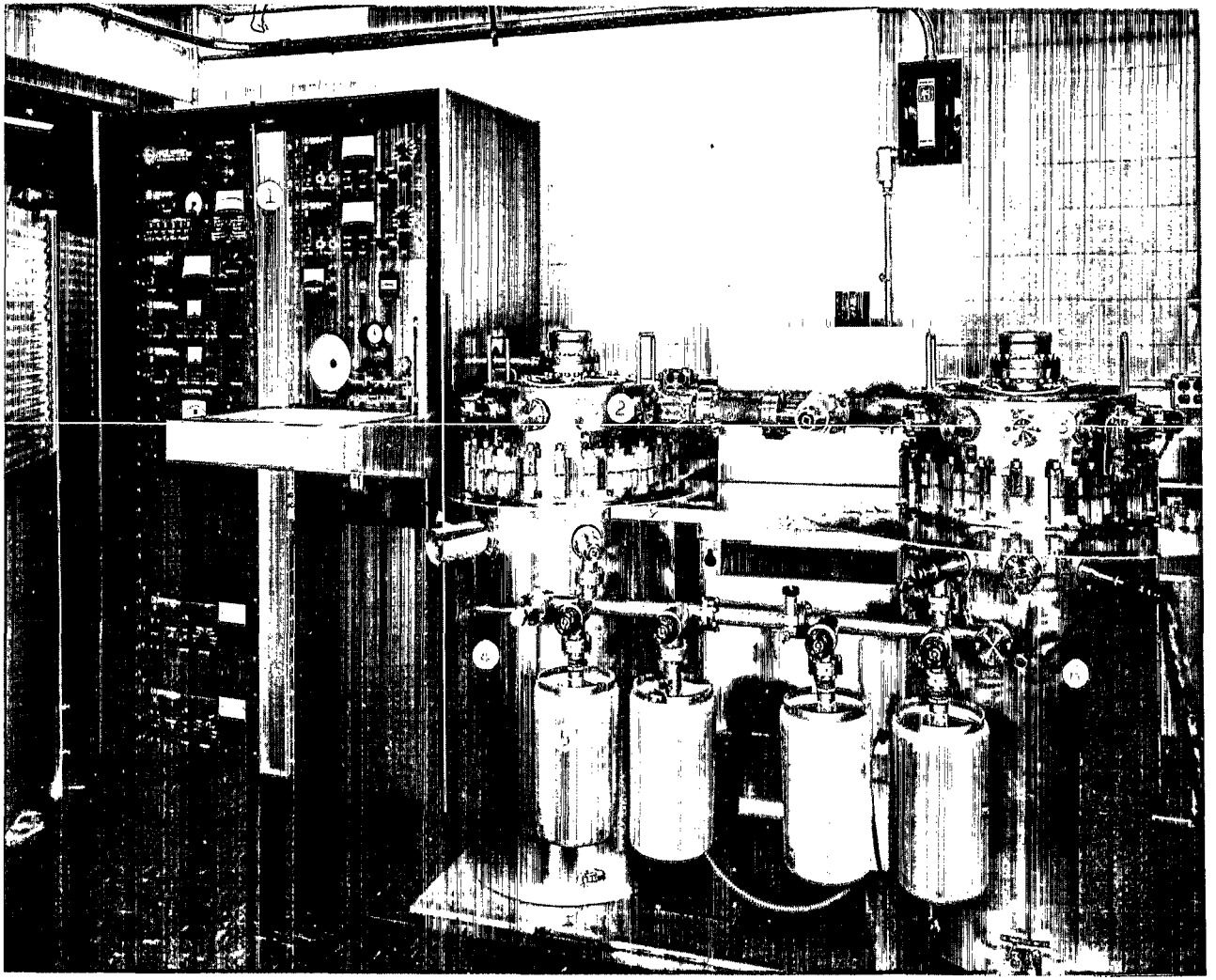


Figure 1.- Block diagram of gas-flow-rate-orifice-conductance calibration system.



① System control panel

② Flow divider chamber

③ Calibration chamber

④ 500 liter/sec ion pump with titanium sublimator

⑤ Cryosorb roughing pumps

⑥ 500 liter/sec ion pump with titanium sublimation on LN_2 surface

Figure 2.- Gage calibration system. L-65-8258.1

① Main power control

② System bakeout control

③ Leak detector

④-⑤ Sublimation pump controls

⑥ Thermocouple control

⑦ Auxiliary electrometer

⑧-⑨ Ion pump controls

⑩-⑪ Operational ion gage controls

⑫ Flowmeter

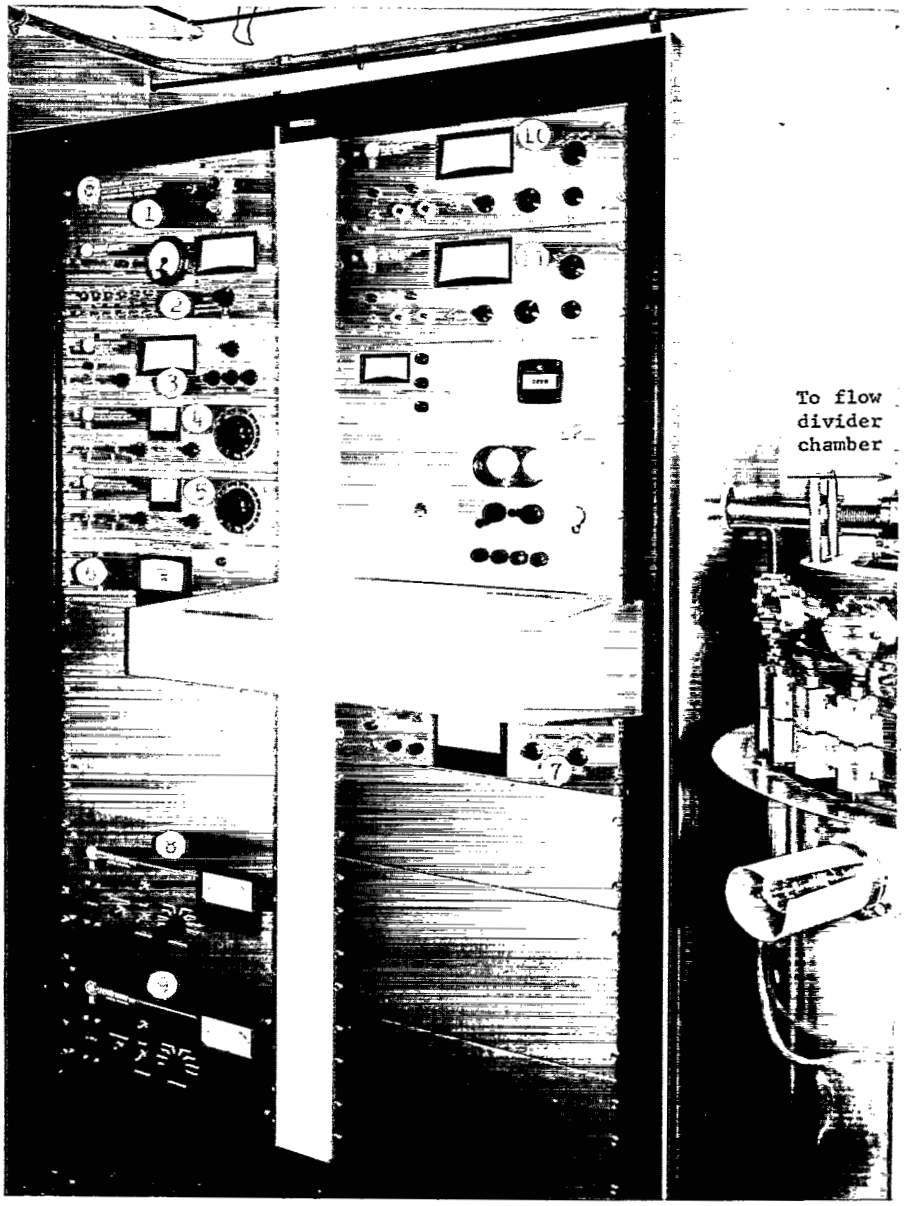


Figure 3.- System control panel. L-65-8261.1

① Electrometer

② Emission regulator

③ Grid and collector voltage

④ ac filament power

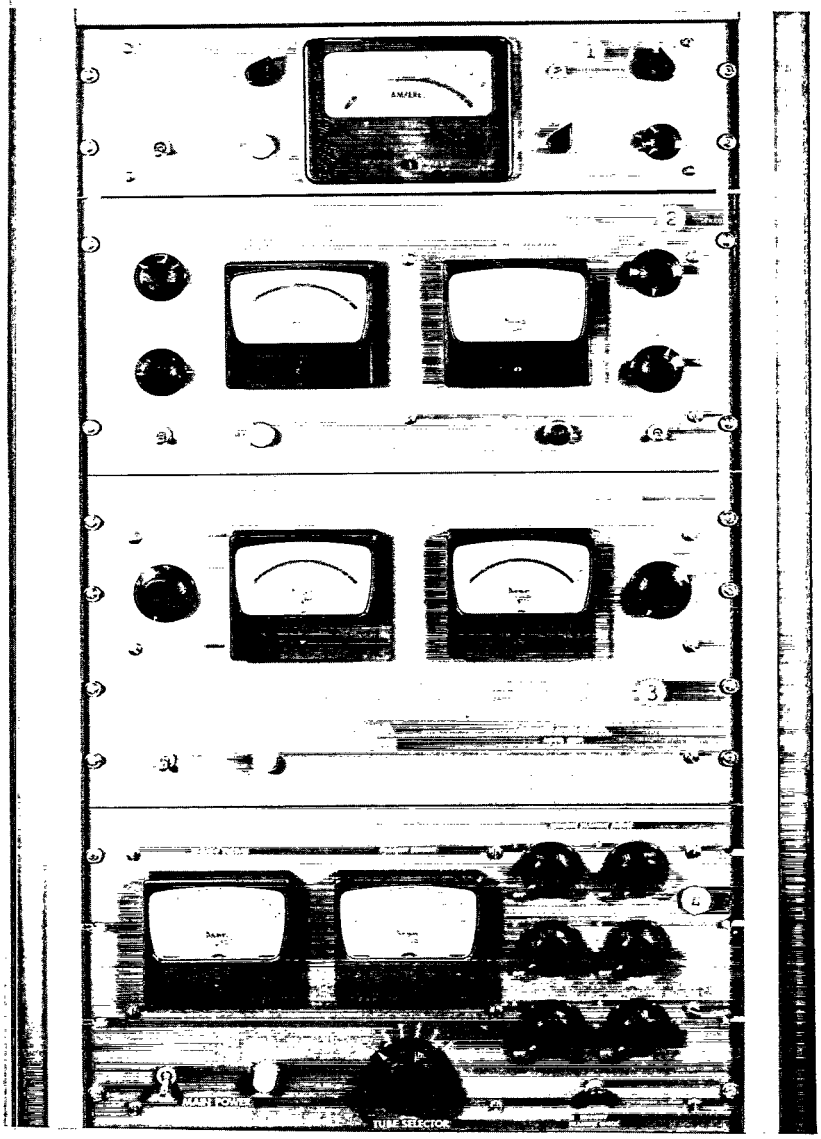


Figure 4.- Precision gage controller. L-65-8260.1

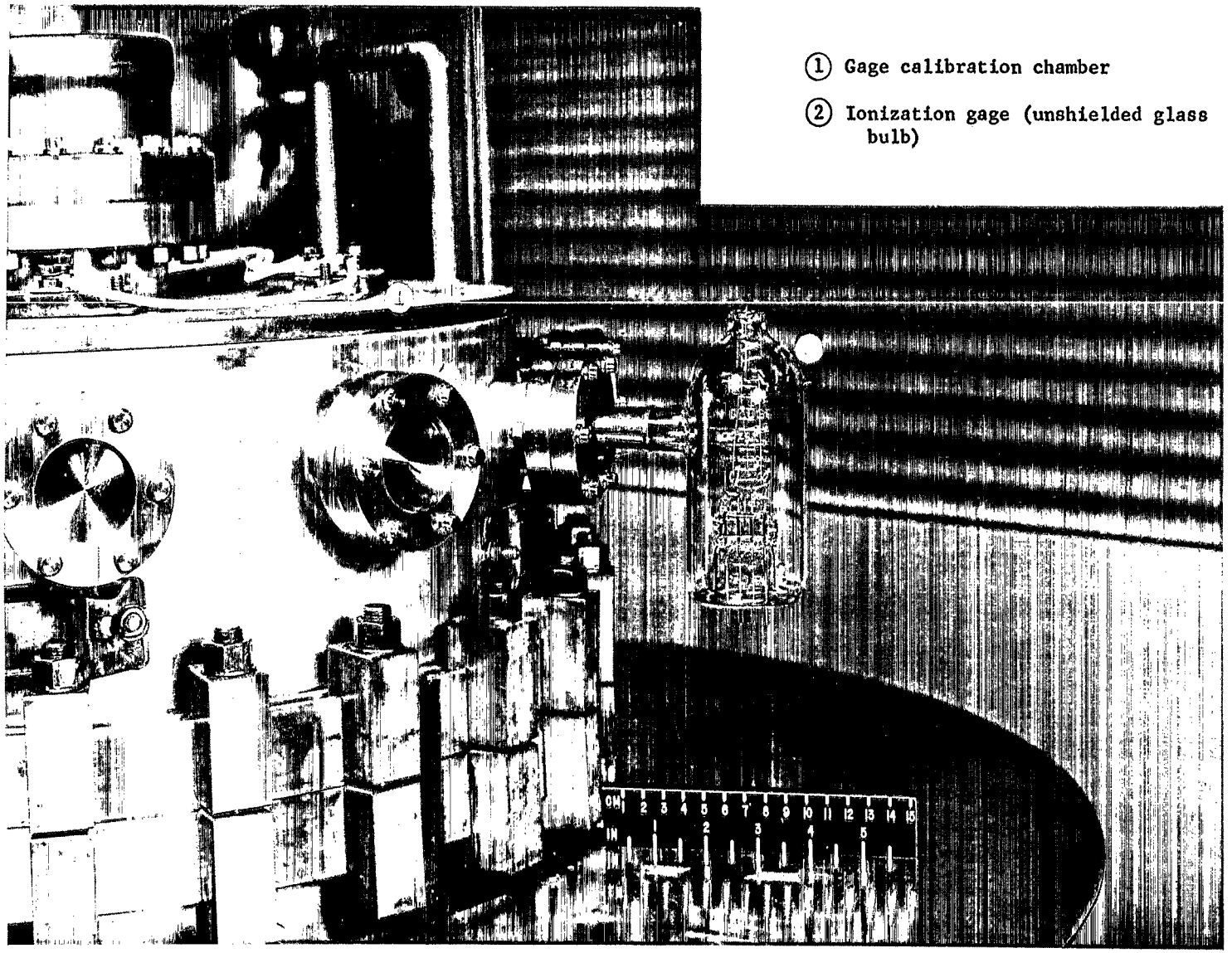


Figure 5.- Unshielded ionization gage on gage calibration chamber. L-65-8257.1

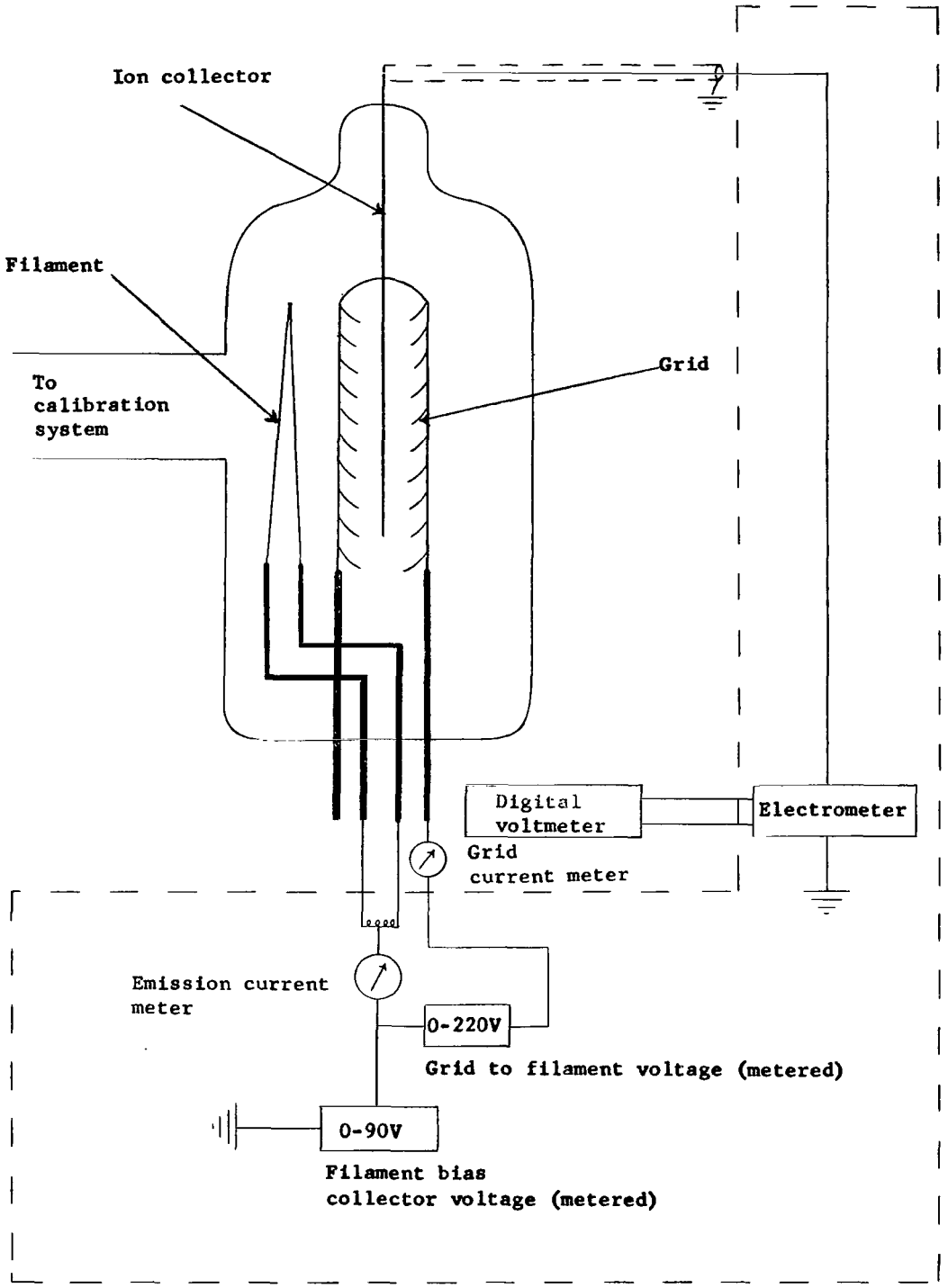


Figure 6.- Cutaway view of Bayard-Alpert ionization gage connected to block diagram of precision gage control less emission regulation and ac power.

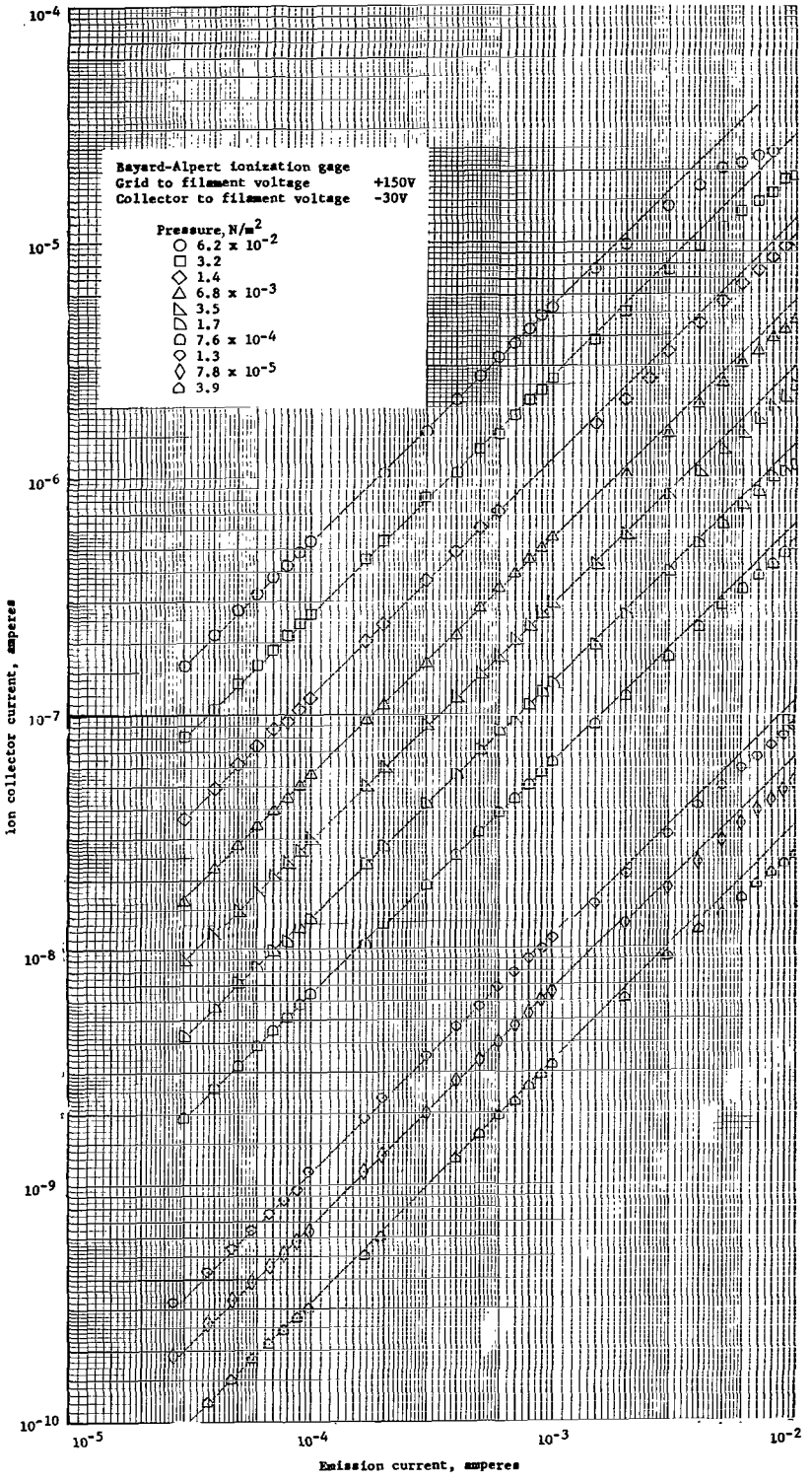


Figure 7.- Ion-emission current characteristic for a Bayard-Alpert ionization gage.

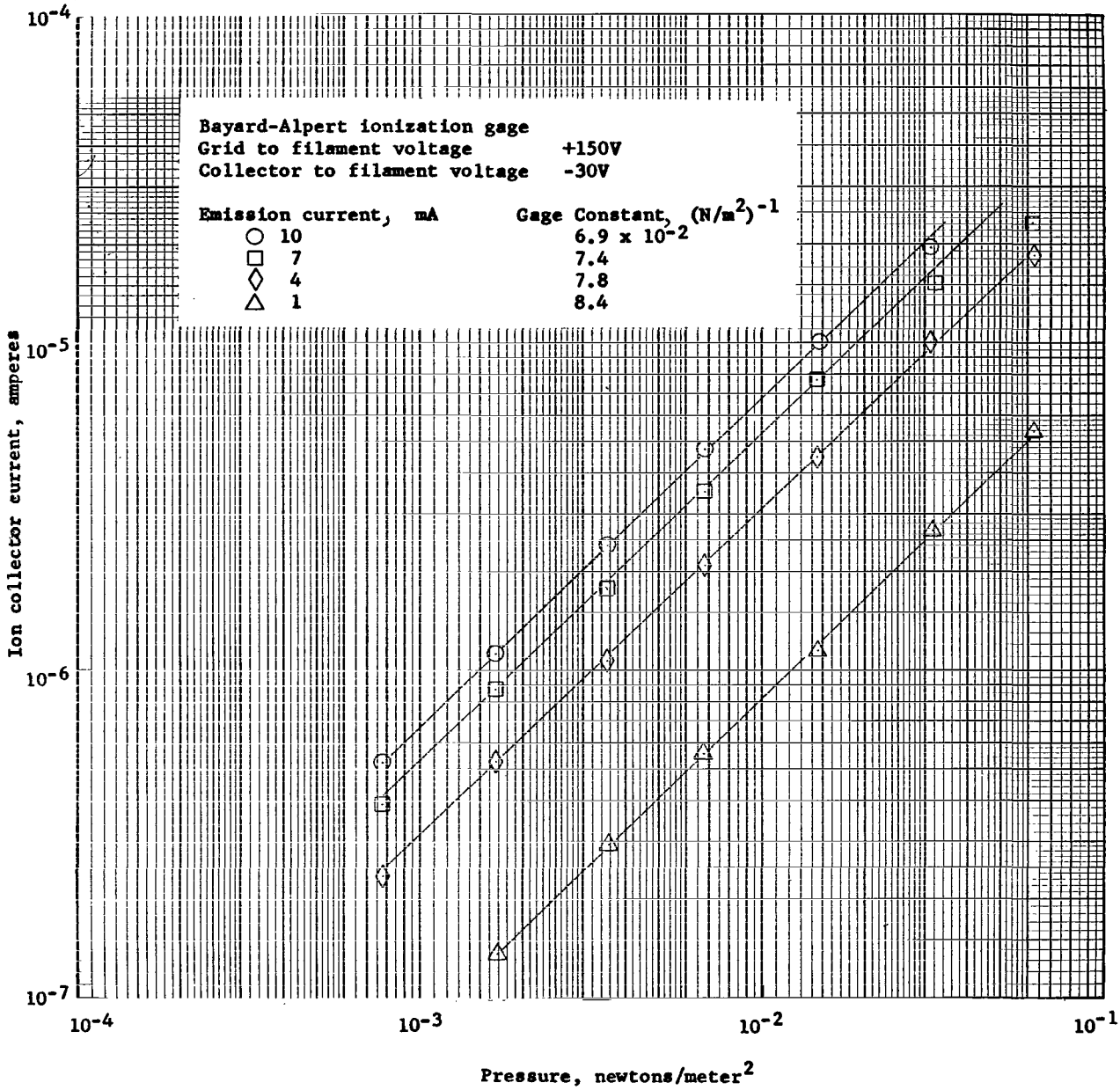


Figure 8.- Bayard-Alpert ionization gage calibration for several emission currents.

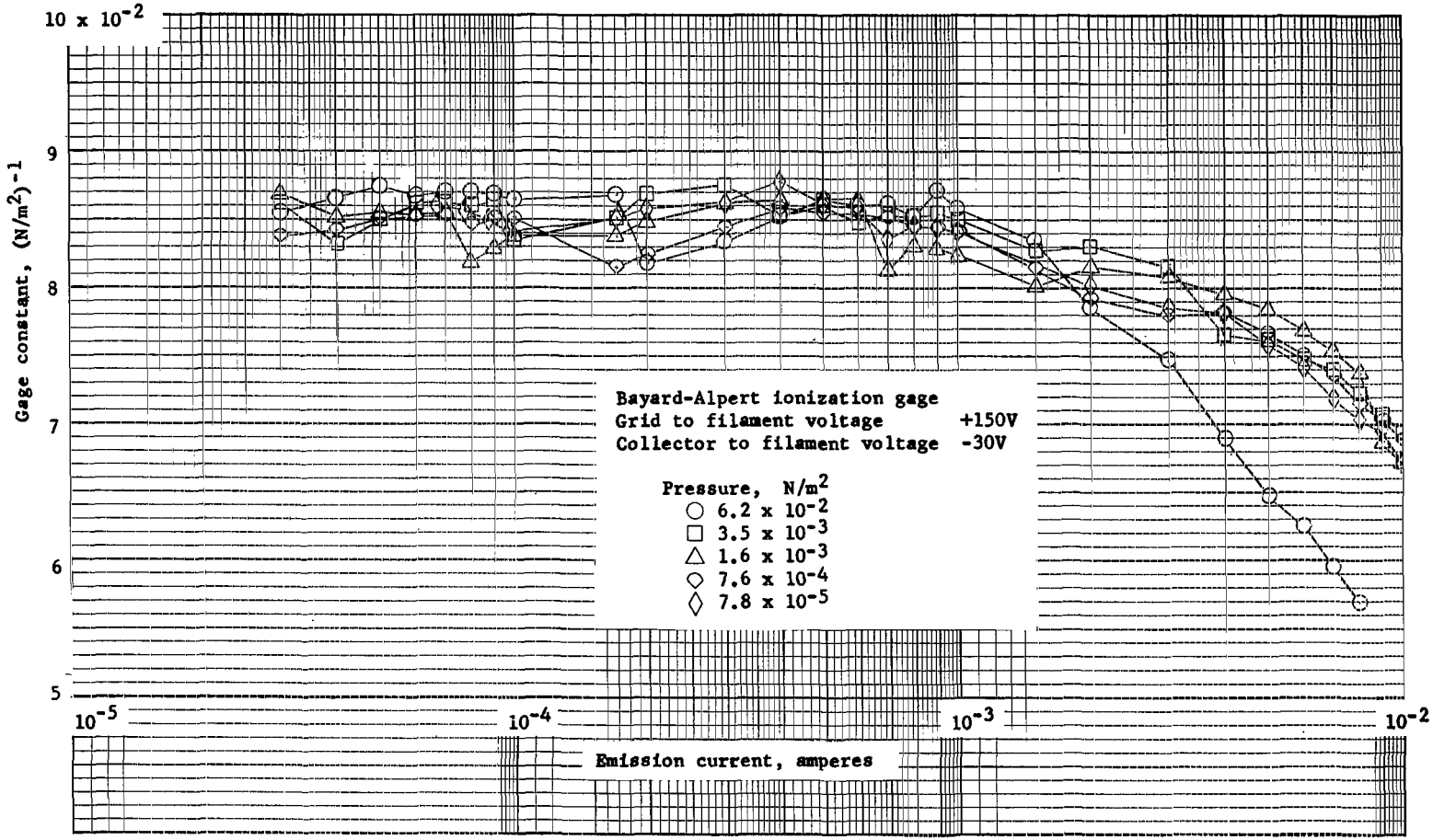


Figure 9.- Gage constant as a function of emission current for several pressures.

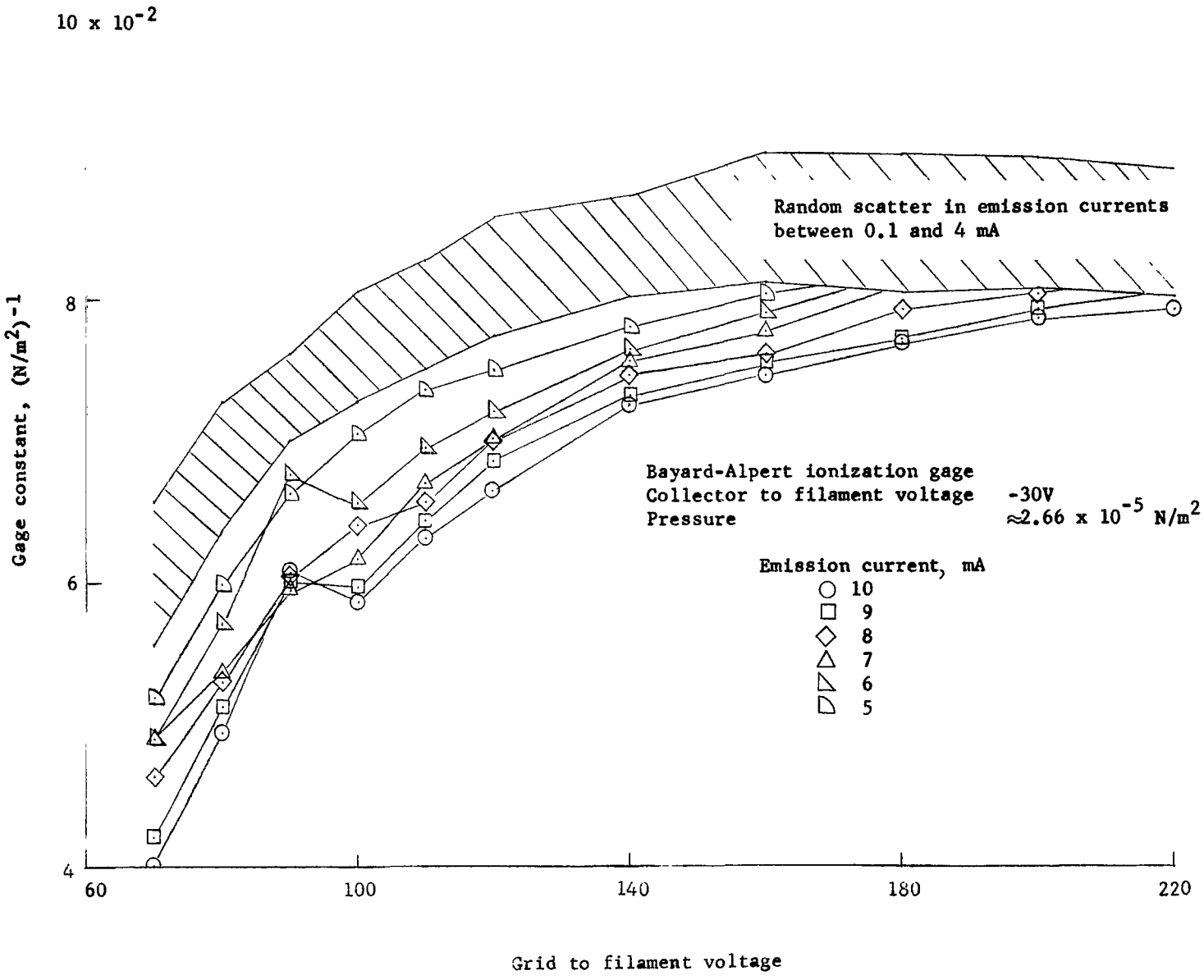


Figure 10.- Gage constant as a function of grid to filament voltage for several emission currents.

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