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NASA TN D-6815
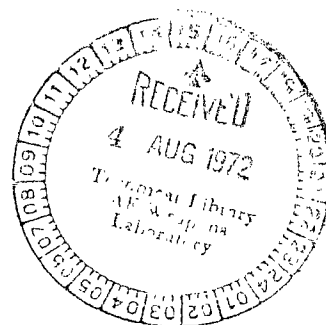
SENSITIVITY OF HOT-CATHODE IONIZATION VACUUM GAGES IN SEVERAL GASES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · WASHINGTON, D. C. · JULY 1972

1. Report No. NASA TN D-6815	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SENSITIVITY OF HOT-CATHODE IONIZATION VACUUM GAGES IN SEVERAL GASES		5. Report Date July 1972
		6. Performing Organization Code
7. Author(s) Raymond Holanda		8. Performing Organization Report No. E-6759
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. 113-31
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words (Suggested by Author(s)) Ionization gage Ionization cross section Vacuum Vacuum measurements		18. Distribution Statement Unclassified - unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified		21. No. of Pages 20	22. Price* $3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

SENSITIVITY OF HOT-CATHODE IONIZATION VACUUM

GAGES IN SEVERAL GASES

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SUMMARY

Four hot-cathode ionization vacuum gages were calibrated in 12 gases. The relative sensitivities of these gages and those of other investigators were compared to several gas properties. Ionization cross section was the physical property which correlated best with gage sensitivity. The effects of gage accelerating voltage and ionization-cross-section energy level were analyzed. Recommendations for predicting gage sensitivity according to gage type were made. The gage sensitivities of this experiment were also compared with the sensitivities obtained by other investigators.

INTRODUCTION

The hot-cathode ionization vacuum gage is the most commonly used gage for the measurement of pressures below 10^{-3} torr. Electrons emitted from the filament of the gage collide with molecules of the gas whose pressure is to be measured, which results in ionization of the gas. The ratio of the resulting ion current to the electron current, divided by a quantity called the gage sensitivity, gives the gas pressure. This gage sensitivity is dependent upon the nature of the gas. The exact nature of this relation has been the subject of much theoretical and experimental investigation.

The problem in determining this relation is that gage sensitivity also depends on other factors, such as the geometry of the gage and the electrical potentials. In addition, the experimental determination of the gage sensitivity introduces the uncertainty of the calibration system itself, and the operation of the experiment requires that the gages be operated in such a way that the following factors remain constant throughout: the electron emission, the temperature of the gage, the structure of the gage (no sagging), the fraction of ions collected, and the electrical potentials. Some of these factors are pressure dependent and further complicate the experiment.

Many investigators have performed experiments to determine the sensitivity of a particular gage for various gases (refs. 1 to 17 and unpublished data obtained at the Lewis Research Center by W. W. Hultzman). Investigators have attempted to correlate the experimentally measured values with some property of the gas. Those properties that have been tried include ionization cross section, first ionization potential, number of molecular electrons, and molecular polarizability.

An analysis of a representative and large sample of the experimental data on gage sensitivity was performed by Summers (ref. 18). He compared these data with peak total ionization cross section and molecular polarizability values. An argument is presented for justifying the selection of these properties as parameters for correlation with gage sensitivity. He concluded that, if the calibration of a particular gage type were known for one reference gas, either of these criteria could be used to predict the sensitivity of the gage for another gas with good accuracy (probable error of 10 to 15 percent); but the accuracy would not be as good as could be obtained by a direct calibration of the gages.

The data used to arrive at these conclusions came from a variety of experiments, covering a span of about 50 years. In many cases, the accuracy of the original data was not stated. It was therefore possible that the probable error of 10 to 15 percent was attributable, at least in part, to the inaccuracies of the calibration facilities. The availability of a calibration system of high accuracy (refs. 19 and 20) prompted the present series of calibrations, in order to determine whether the correlation between gage sensitivity and some gas property would thereby be improved.

This report presents the experimental determination of gage sensitivity for four gages in 12 different gases. A secondary objective was to correlate these high-accuracy calibrations with the work of previous investigators.

EXPERIMENTAL PROCEDURE

The gases used in these experiments were helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), dry air, oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), nitrogen (N_2), and sulfur hexafluoride (SF_6). These gases were research grade, of 99.9 percent purity. The four hot-cathode ionization gages calibrated were of the Bayard-Alpert type. The gages were identical except for the filaments. Gages W and X had thoriated-iridium filaments; gages Y and Z had tungsten filaments. Gages W and X were calibrated while simultaneously mounted on the same flange, side by side, with the filaments in the vertical position. They were then replaced by gages Y and Z, and the calibration was repeated, after appropriate reevacuation and bakeout of the system.

The ionization gage control units were standard commercially available units modified to provide measurement and control of the emission current to ±0.3 percent of the reading throughout these experiments and measurement of the collector current to ±1/2 percent of the reading.

The volume-ratio calibration system is described in reference 20. It is basically a device for transferring measured quantities of test gas from a source volume into a previously evacuated and sealed test chamber. The calibrating range of the system is 10^{-8} to 10 torr. An error analysis (ref. 20) showed that pressures could be produced with a limit of error of ±$1\frac{1}{2}$ percent between 10 torr and 10^{-6} torr, the error increasing from ±$1\frac{1}{2}$ percent at 10^{-6} torr to ±4 percent at 10^{-8} torr. The calibrations were performed in the pressure range from 10^{-7} to 10^{-5} torr. In this range the calibration system has a limit of error of about ±2 percent.

Each calibration run consisted of 3 to 10 points. A minimum of 5 calibration runs and 25 calibration points were obtained for each test gage in each test gas, with two exceptions. (The exceptions were gages W and X in CO and O_2. Here, because of fear of damage to the gage filaments, only 17 points were taken for CO and 8 for O_2.) The calibration runs on a given gage for each gas were spread out over a minimum of 5 days to eliminate any systematic effects that history of the gage or test chamber might have on experimental results.

A mass spectrometer was used to monitor the purity of the test gas as it was injected into the system, to determine whether the gas handling system was operating properly. The purity of the gas injected into the system was estimated to be 98 percent or better.

The use of four different gages in the experiment improved the statistical validity of the results and facilitated comparison with calibrations obtained by other investigators. Twelve different gases were used, to make the experiment as broad in scope as possible. Only one other experiment (ref. 6) used so many gases. Two commonly encountered filament materials were used to compare the effects of the active gases on different filaments.

RESULTS AND DISCUSSION

Calibration of Gages

The results of the calibrations are presented in table I. The sensitivity S of the gage to each gas is presented relative to nitrogen sensitivity S_{N_2}. Error is defined as the deviation from the mean curve of sensitivity as a function of pressure for a particular gas. Limit of error is defined as the error that is not exceeded by more than 10 percent of the data points. The limit of error of the data was slightly lower for the noble gases

than for the active gases. The repeatability of gage W was not quite as good as that of the other three gages, but for no apparent reason.

Also included in table I is the arithmetic average of the relative sensitivities of gage combinations W + X, Y + Z, and W + X + Y + Z.

The only gas that presented any serious problems in the calibration procedure was oxygen. In the case of the thoriated-iridium filament (gages W and X), the oxygen had a tendency to decrease the emission. In the case of the tungsten filament (gages Y and Z), the sensitivity increased or decreased with increasing increments of pressure, depending on the occasion, but became asymptotic to the same stable value at sufficiently high pressures. However, this stable value was suspiciously low compared with that obtained by other investigators and suggested some kind of chemical change or reaction. In both cases the changes were reversible and had no permanent effect on the gage.

The result of these problems was that, for gages Y and Z, the limit of error for oxygen is much greater than for any other gas. Also, to minimize the possibility of gage damage, fewer data points were taken for gages W and X. A slight emission instability was also experienced when CO was measured with the thoriated-iridium filament. No other trouble was experienced in using the volume-ratio calibration system as a standard with the various gas environments.

The only variation in the calibration operation from one gas to the next was the rate of change of pressure with time in the closed system. This was primarily a function of the pumping speeds of the gages and the outgassing rate of the system. The gage pumping speeds were the smallest for the noble gases and largest for oxygen and further complicated the oxygen calibrating procedures.

A few examples of the calibrations from which table I was compiled are shown in figure 1. The ordinate is the calibration factor, which is the quantity that the gage reading must be multiplied by to be converted to pressure.

Correlation of Gage Sensitivity With Molecular Properties

The data of this report are compared with the data of other experimenters and with various molecular properties of the gas. Since the uncertainty in knowledge of gage sensitivity may be comparable to the uncertainty in knowledge of some of these properties, the measure of comparison has been chosen to be the coefficient of correlation r, which is given by the formula

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \tag{1}$$

where x_i and y_i are the data points and

$$\bar{x} = \frac{\sum x_i}{n}$$

$$\bar{y} = \frac{\sum y_i}{n}$$

for n data points.

This factor indicates how well a linear equation describes the relation between the two variables. A perfect correlation is $|r| = 1$. A value of $r = 0$ shows no correlation, and $|r| \geq 0.9$ can be considered a strong linear correlation. The extent to which two values of r may be considered to be significantly different is suggested by their probable errors δr; this quantity depends on the values of r and n and is defined as the 50 percent confidence band of the correlation coefficient. The method of determining this quantity is that used in reference 21.

In order to allow for the fact that all measurements have equal probable fractional error, rather than equal probable absolute error, $\ln x_i$ and $\ln y_i$ are substituted in equation (1) instead of x_i and y_i. This is tantamount to plotting the measured data on log-log paper. This method of plotting is particularly necessary because the relative sensitivity covers a range of about 20 to 1.

The equation that is fitted to the data is thus

$$\ln y = \ln C + m \cdot \ln x \tag{2}$$

Figure 2 is an example of such a plot for some of the data of this report, as computed from equation (1). The correlation coefficient for this graph is 0.972.

Figure 3 presents the correlations obtained between gage sensitivity measured in this experiment and various properties of the gas, as well as the probable error (50 percent confidence band) of the correlation coefficient. Each of these gas properties has been cited by one or more investigators as a possible criterion for correlation with gage sensitivity. The actual values of these various properties are listed in table II. The ionization-cross-section data are those of reference 22, based upon the recommendation of reference 18. Reference 22 gives ionization-cross-section data for 16 different gases in the energy range from 10 to 1000 electron volts. The molecular polarizability data are obtained from reference 18, compiled in part from reference 23. The choices made by reference 18 result from critical surveys of the literature. All of these properties

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are related to the general concepts of molecular size and ability to be ionized, which are fundamental to the operation of the ionization gage.

From figure 3 it can also be seen that many gas properties correlate well with gage sensitivity and can be used as a satisfactory guide in predicting sensitivity in the absence of a direct calibration. Ionization cross section is the molecular property which provides the best correlation, as expected from previous investigations (ref. 18). Therefore, this property will be investigated in more detail in this report.

Figure 4 shows how the coefficient of correlation of gage sensitivity with ionization cross section varies at electron energies from 30 to 1000 electron volts for gages W, X, Y, and Z. (Data for SF_6 are not included in this figure because the ionization-cross-section data of ref. 21 only cover the range 26 to 300 eV. The cross section of dry air is obtained by proportionate summation of the cross sections for N_2, O_2, and Ar.)

The tungsten-filament gages show distinct maximums in correlation coefficient at an electron energy that is about one-half the maximum energy (150 V, the gage accelerating voltage). The iridium-filament gages also have very high correlation at this energy, although the peak is very flat.

Reference 18 notes that a good guide to predicting gage sensitivities is the maximum value of ionization cross section for each gas. The correlation coefficient thus obtained is shown in figure 4 by the symbols. It has been placed at 100 electron volts as an average of the range of most of the maximum values. (The maximum value of ionization cross section of 10 of the gases occurs in the range 70 to 125 eV; for neon it is 187 eV.) The correlation compares favorably with those obtained at a specific electron energy level in the 75 to 100-volt range, and either method could be recommended for predicting gage sensitivity for these gages.

Figure 5 is a graph for a representative group of Bayard-Alpert gages, other than those tested in the present experiment. As in figure 4, a gage sensitivity based on either 100-electron-volt ionization cross sections or the maximum value of ionization cross section for each gas would result in a high r. Note that this conclusion is applicable for gages with accelerating voltages varying from 130 to 260 volts. But, again as in figure 4, there is no simple relation between gage accelerating voltage and the electron energy at which peak r occurs.

Figure 6 is a graph of triode gage correlation coefficients. Some of the references are very old, and some of the voltage information is incomplete, so the basic gage sensitivity data probably lack the overall accuracy associated with the Bayard-Alpert gages. Reference 1 is especially subject to question, as pointed out in reference 24. With the exception of references 1 and 4, either a 100-electron-volt ionization cross section or a maximum ionization cross section would be a satisfactory guide to gage sensitivity prediction. And as in Bayard-Alpert gages, a consistent ratio between gage accelerating voltage and the electron energy at which peak r occurs does not exist.

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It was thought that a gage of simpler geometry might show a more consistent pattern of electron energy effects. The high-pressure ionization gages provide such a geometry, with plane parallel electrodes in most designs and short electron path lengths. Figure 7 is a graph of the correlation coefficient as a function of the ionization cross section at various electron energies for five different high-pressure ionization gages. References 6, 8, 17, and 25 and unpublished Lewis data provided the experimentally determined gage sensitivities for this comparison. Note the following relation between gage accelerating voltage and electron energy at peak correlation coefficient:

Reference	Gage electron accelerating voltage, V	Electron energy at peak correlation coefficient, eV
25	43	26
17	60	40
8	60	50
Unpublished Lewis data	135	90
6	180	150

A general trend is indicated, with the correlation coefficient peaking at a value about seven-tenths of the accelerating energy.

The symbols in figure 7 again represent the correlation obtained by using the maximum value of ionization cross section for each gas. Note that for these gages this is not a good criterion for predicting gage sensitivity. The general rule that can be clearly seen from this graph is that the solid symbols occur at approximately the same point as the 100-electron-volt ionization cross section, because this is about where the maximum value of ionization cross section averages out. In some cases this results in a high r and in others a low r, because 70 percent of the accelerating voltage may or may not be close to 100 volts.

A vacuum gage with a high-energy ionizing source (about 5000 eV) is the Alphatron gage. Reference 26 and unpublished manufacturer's data give sensitivities of the Alphatron gage for various gases. Figure 8 shows that the correlation coefficient is still increasing at 1000 electron volts. It appears evident that the correlation coefficient will peak near the value of the energy level of the ionizing source.

From this analysis it can be seen that, when the gages are analyzed according to type, individual characteristics of gage sensitivity become evident which result in different criteria being selected for the best correlation with ionization cross sections. In summary, the following recommendations are made:

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(1) For Bayard-Alpert ionization gages, either a 100-electron-volt ionization cross section or a maximum ionization cross section for each gas is a satisfactory physical property to correlate with gage sensitivity. These conclusions were applicable for gages ranging in accelerating voltage from 130 to 260 volts, including the four gages calibrated for this report. Because of the physical complexity of these gage structures and resulting potential fields, a clear-cut relation between gage accelerating voltage and peak r does not occur.

(2) For triode ionization gages, the same conclusions as in item (1) apply, with the qualification that the data available for triode gages are older and perhaps less reliable.

(3) For the high-pressure ionization gages, the ionization cross section at an energy which is about 70 percent of the gage accelerating voltage is the physical property which gives a good correlation with gage sensitivity. Because of a wide range in accelerating voltage among these gages (43 to 180 V), the ionization cross section at a single value of electron energy would not be a good guide to correlation. Very high correlations were obtained with these gages, possibly because of their simpler geometries.

(4) For the Alphatron gage, ionization cross sections at energies of about 1000 electron volts (or higher, if data are available) provide a good correlation with gage sensitivity.

Another variable that has an important effect on the correlation is the nature of the gases. Figure 9 shows the correlation obtained for gage W of this experiment by using different groups of gases. With each different combination of gases chosen for linear correlation, a different curve results. The significant differences that are shown in figure 9 are the following:

(1) The noble gases (He, Ne, Ar, Kr, and Xe) have the highest correlation of ionization gage sensitivity with ionization cross section without regard to the energy level.

(2) The active gases (O_2, CO, CO_2, N_2, H_2, and air) have a correlation coefficient considerably lower than that for the noble gases because of the occurrence of a complex pattern of gas dissociation, subsequent reaction of the dissociation products with vacuum-system surfaces, and reemission of reaction products. Reference 24 discusses some of these problems.

(3) The curve for all 12 gases goes to only 300 electron volts because reference 22 has data for SF_6 only to this value. It is not significantly different from the curve for the other 11 gases through this region.

Correlation of Gage Sensitivity Data With Other Experimenters

The correlation coefficient is a convenient way to compare the sensitivities obtained in the present experiments with those obtained by other experimenters over the last 50 years. These correlations are shown in table III. The coefficient in the table represents

the correlation between the average of the four gage sensitivities obtained in the present experiment and the average of the sensitivities obtained by the other experimenter. There is a great variety represented by these experiments regarding type of gage, number of gases tested, nature of gases tested, and calibration techniques. Despite this great variety, the correlation coefficients are, with few exceptions, very good, and in many cases, almost perfect.

Reference 13 provides the highest correlation coefficients, but this is mainly due to the facts that the work was limited to the five noble gases (He, Ne, Ar, Kr, and Xe) and the same gage type and model were used as in the present experiment. Reference 11 also used these same gases with excellent correlation. In some cases (refs. 10 and 14), the number of gases was too small to obtain a significant coefficient.

Particular weight can be attached to reference 15 because it has the most gases in common with this report (10), uses the same gage type, is of relatively recent vintage (1966), and states the reproducibility of the results to be ±2 percent for most of the data, which is very high for this type of work. (In most other reports, the accuracy or reproducibility is not even mentioned, and the evaluation of the results is difficult.) The high correlation coefficient indicates that the sensitivities reported in reference 15, for gases other than those used in the present experiment, may confidently be assumed to apply to the present gages, and that the sensitivities so predicted are more accurate than those that would be predicted from the correlations with ionization cross section.

Reference 18 has compiled an average of 15 references but lumps together gages without regard to type. The coefficient of correlation between this "average gage" sensitivity and the present data is not so high as that obtained with reference 15 but is about equal to the correlation coefficients that appear in figure 2.

CONCLUDING REMARKS

Four hot-cathode ionization vacuum gages were calibrated in 12 different gases. A volume-ratio calibration system was used to perform the calibrations with a limit of error of about ±2 percent. The system proved suitable as a standard in the various gas environments. Difficulty was experienced with the gage filaments in the presence of oxygen.

The relative sensitivities of these gages and those of other investigators were compared to several gas properties. In general, ionization cross section was the physical property which correlated best with gage sensitivity. Correlating the gage sensitivity with the ionization-cross-section energy level, showed that the rule for predicting gage sensitivity most accurately varied according to gage type. In summary, the following recommendations were made:

(1) For Bayard-Alpert gages and for triode gages, either a 100-electron-volt ionization cross section or a maximum ionization cross section for each gas gave a good correlation with gage sensitivity.

(2) For high-pressure ionization gages, an ionization cross section at an energy which is about 70 percent of the gage accelerating voltage provided a good correlation with gage sensitivity.

(3) For the Alphatron gage, a 1000-electron-volt ionization cross section gave a good correlation with gage sensitivity.

The relative gage sensitivities of this experiment were compared with those obtained by other investigators. The results show many good correlations obtained despite the presence of a great variety of gage types, gases, calibration facilities, and procedures. A comparison of these gage sensitivities with an average of much of this data resulted in a correlation coefficient about equal to the correlation obtained with ionization cross section.

Lewis Research Center,
　　National Aeronautics and Space Administration,
　　　　Cleveland, Ohio, May 2, 1972,
　　　　　　113-31.

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TABLE I. - EXPERIMENTAL RESULTS OF GAGE CALIBRATION

Gas	Gage											
	W	X	Y	Z	W	X	Y	Z	Average	W + X	Y + Z	W + X + Y + Z
	Relative sensitivity, S/S_{N_2}				Limit of error, percent					Average relative sensitivity, $(S/S_{N_2})_{av}$		
Nitrogen	1.00	1.00	1.00	1.00	±8	±4	±5	±4	±5	1.00	1.00	1.00
Helium	.164	.172	.188	.190	4	5	5	5	5	.168	.189	.178
Neon	.305	.321	.32	.32	2	3	5	5	4	.313	.32	.316
Argon	1.37	1.42	1.44	1.46	8	4	6	4	6	1.40	1.45	1.42
Krypton	1.89	1.94	1.95	2.00	4	2	4	4	4	1.92	1.98	1.94
Xenon	2.78	2.82	2.80	2.83	4	2	3	4	3	2.80	2.82	2.81
Hydrogen	-----	-----	.41	.41	--	--	6	6	6	-----	.41	.41
Oxygen	.92	.82	.69	.67	(a)	(a)	15	15	15	.87	.68	.78
Carbon monoxide	1.00	.97	1.04	1.04	7	6	5	6	6	.98	1.04	1.01
Carbon dioxide	1.47	1.37	1.36	1.36	10	4	5	6	6	1.42	1.36	1.39
Dry air	.89	.92	.93	.92	9	5	7	7	7	.90	.92	.91
Sulfur hexafluoride	2.36	2.04	2.26	2.14	7	4	4	5	5	2.20	2.20	2.20

[a]Insufficient data.

TABLE II. - VALUES OF MOLECULAR PROPERTIES USED FOR CORRELATION

WITH IONIZATION GAGE SENSITIVITY

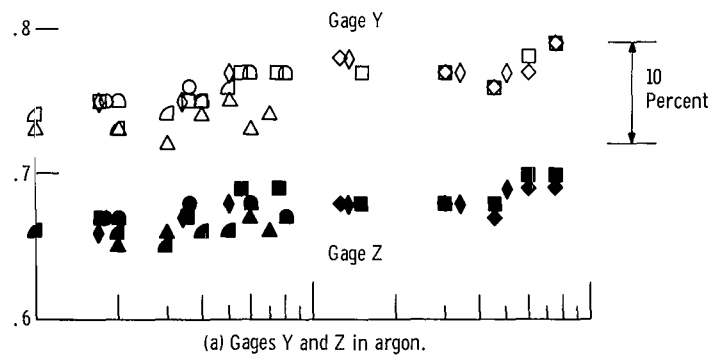| Gas	Physical property					
	Number of molecular electrons	Molecular polarizability, cm^3 (a)	First ionization potential, V (b)	Multiples of πa_o^2 (c)		
				Peak ionization cross section	150-eV ionization cross section	34-eV ionization cross section
Helium	2	2.1×10^{-25}	24.5	0.425	0.419	0.13
Neon	10	3.7	21.5	.89	.878	.175
Argon	18	16.5	15.7	3.25	3.05	2.4
Krypton	36	----------	13.9	4.84	4.35	3.56
Xenon	54	----------	12.1	6.21	5.90	4.76
Nitrogen	14	17.6	15.5	2.874	2.79	1.44
Hydrogen	2	7.9	15.6	1.104	.924	.882
Oxygen	16	16.0	12.5	3.08	3.06	1.31
Carbon monoxide	14	19.5	14.1	3.018	2.92	1.70
Carbon dioxide	22	26.5	14.4	4.04	3.96	2.02
Air	--	17.2	----	2.91	2.85	1.42
Sulfur hexafluoride	70	----------	----	7.92	-----	-----

[a]Ref. 18.

[b]Ref. 25.

[c]Ref. 21; a_o is the radius of the first Bohr orbit of atomic hydrogen, 0.53×10^{-8} cm.

TABLE III. - COMPARISON OF IONIZATION GAGES OF THIS

REPORT WITH THOSE OF OTHER INVESTIGATORS

Reference	Year	Number of gases	Gage type	Correlation coefficient, r	Probable error of r
1	1924	5	Triode	0.945	+0.03 -.08
[a]3	1945	7	Triode	.993	±.004
4	1951	5	Triode	.998	±.002
4	1951	5	Suppressor	.989	±.007
5	1951	6	Triode	.955	+.02 -.05
6	1955	9	High pressure	.967	+.015 -.025
7	1957	6	Bayard-Alpert	.998	±.002
8	1957	4	High pressure	.983	+.01 -.04
9	1960	5	Bayard-Alpert (RG-75)	.958	+.03 -.07
9	1960	5	Triode	.965	+.02 -.05
10	1961	3	Bayard-Alpert	(b)	------
11	1961	5	Bayard-Alpert	.998	±.002
12	1963	4	Bayard-Alpert (RG-75)	.897	+.07 -.25
13	1964	5	Bayard-Alpert (RG-75)	1.00	------
14	1966	3	Bayard-Alpert (RG-75)	(b)	------
15	1966	10	Bayard-Alpert	.999	±.001
16	1966	6	Pentode	.936	+.03 -.07
17	1968	7	High pressure	.954	+.02 -.04
Unpublished Lewis data	1971	10	Bayard-Alpert	.994	±.004
Unpublished Lewis data	1971	10	Bayard-Alpert (RG-75)	.981	+.007 -.012
Unpublished Lewis data	1971	10	High pressure	.986	±.007
18	1969	11	All types	.993	±.004

[a]Average of three gages.

[b]Insufficient data for significant correlation.
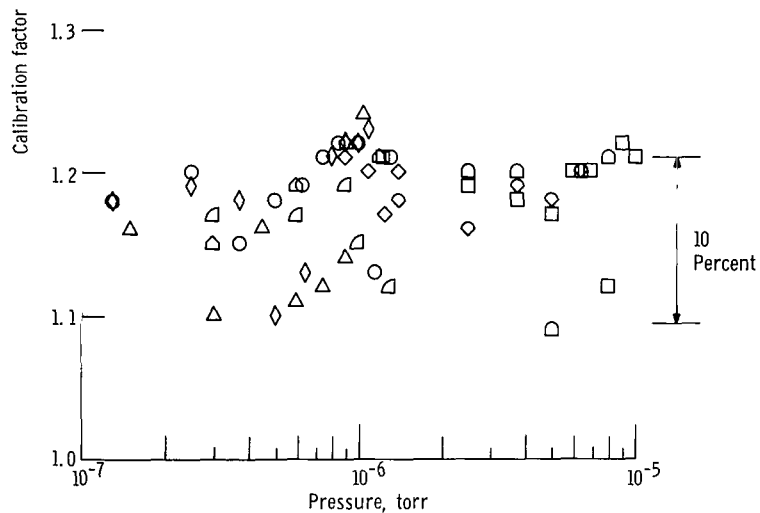
Figure 1. – Calibrations of gages Y and Z. Different symbols represent individual calibration runs.

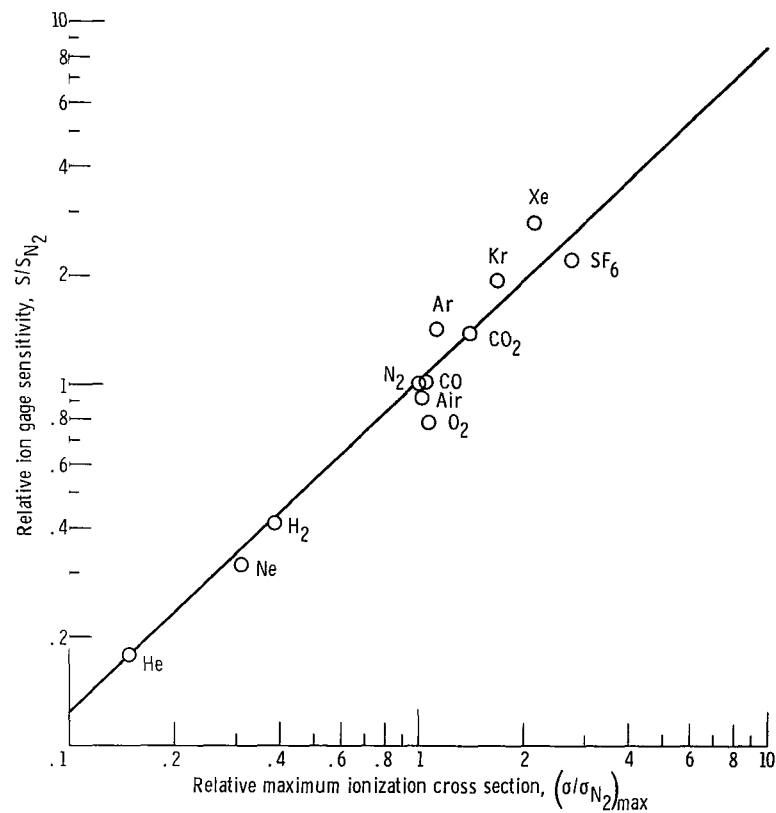(a) Gages Y and Z in argon.

(b) Gage Y in air.

Figure 2. – Relative ion gage sensitivity as function of maximum ionization cross section for average value of gages W, X, Y, and Z.
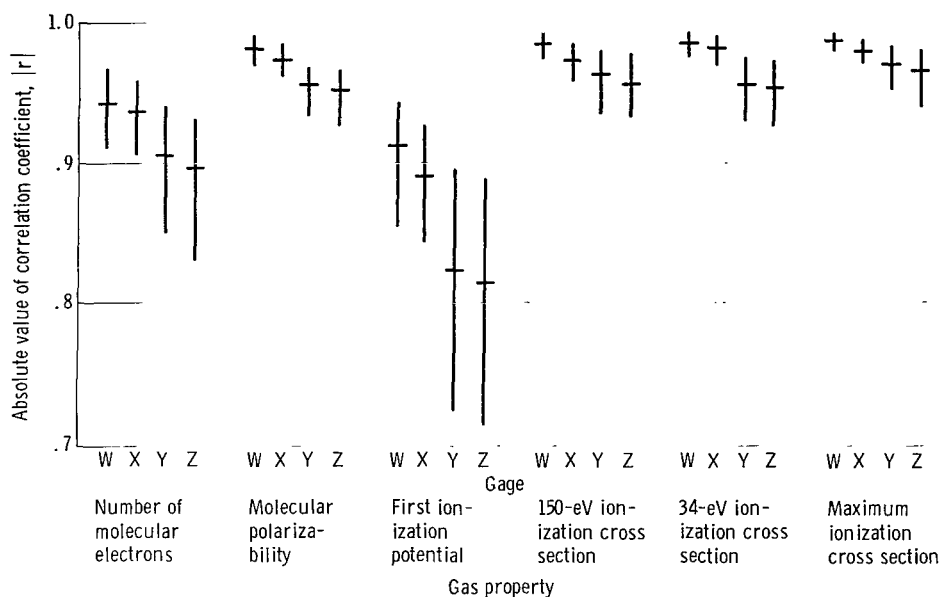
Figure 3. - Correlation coefficients showing comparison of sensitivities of ionization gages W, X, Y, and Z to various gas properties. Vertical lines represent probable errors; no molecular polarizability data for Kr, Xe, and SF_6; no first ionization potential data for air and SF_6; no ionization cross section data for SF_6; correlation coefficients for first ionization potential are negative.
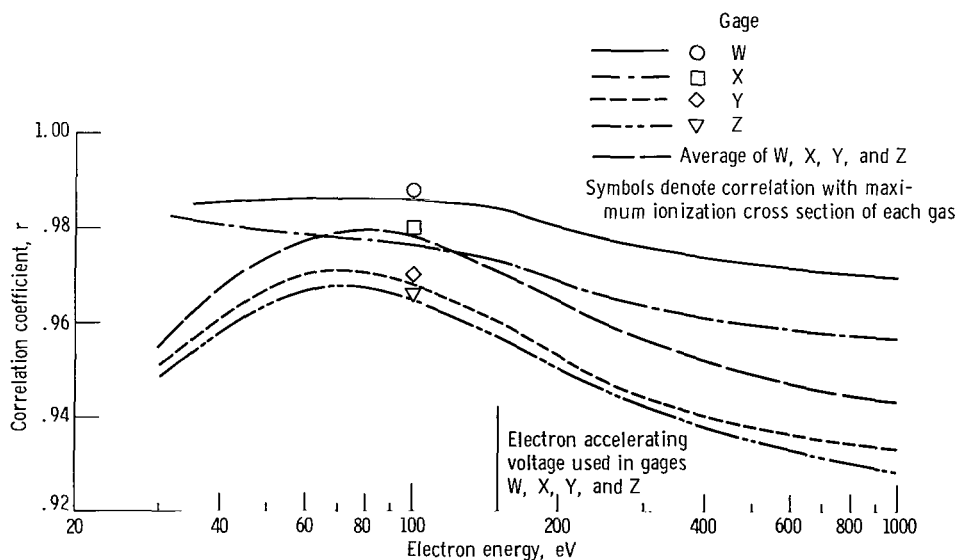
Figure 4. - Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for gages W, X, Y, and Z.
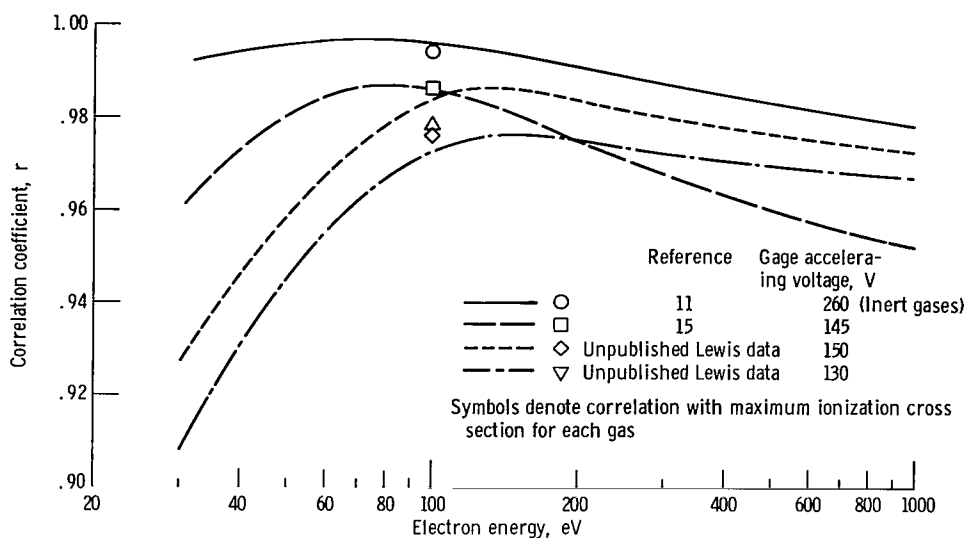
Figure 5. - Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for Bayard-Alpert ionization gages.
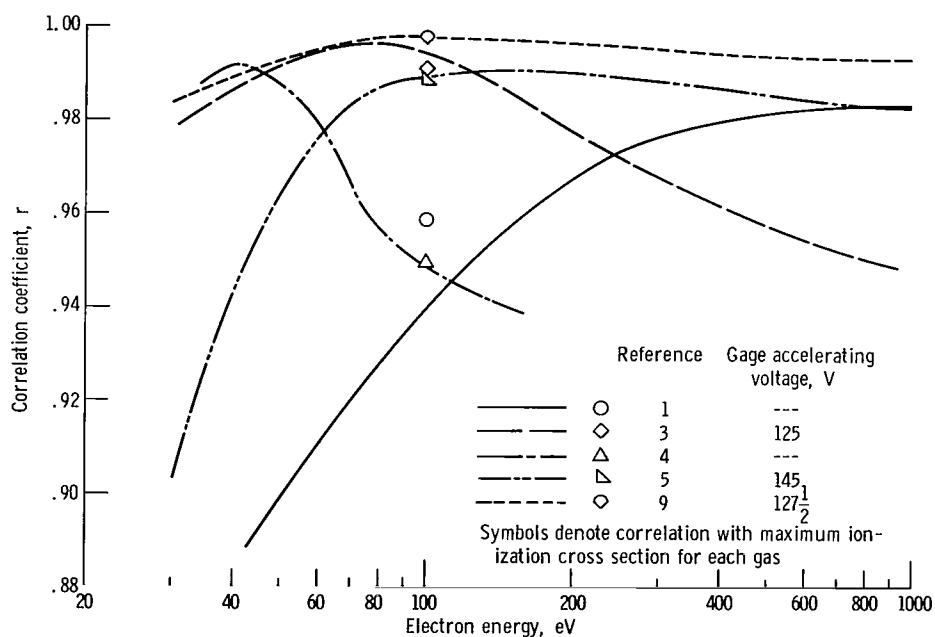
Figure 6. - Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for triode ionization gages.
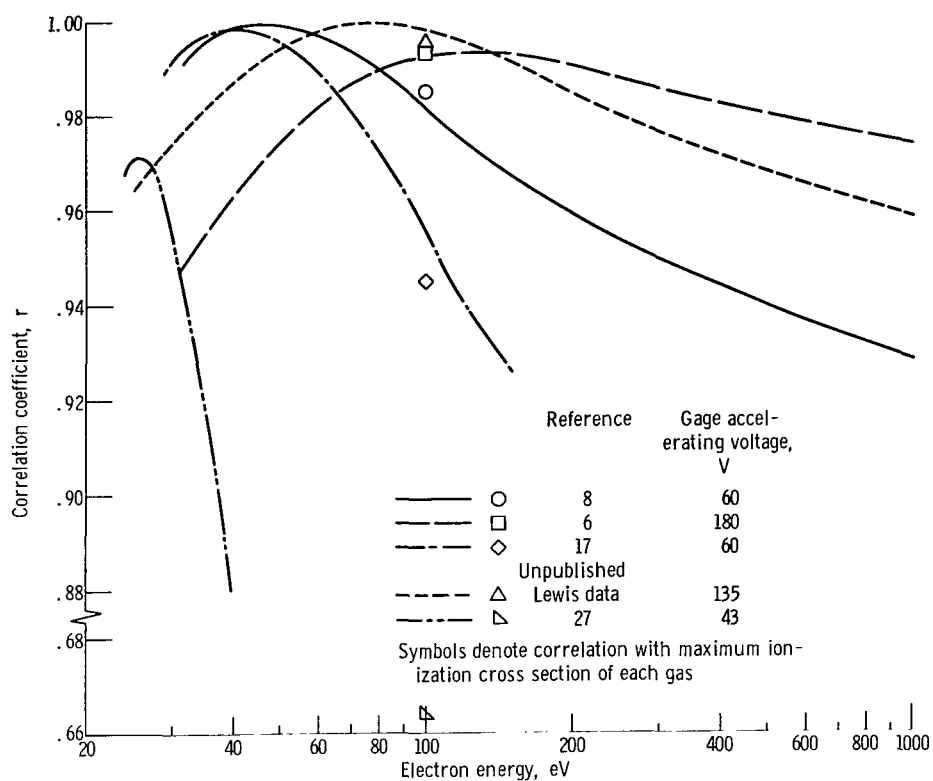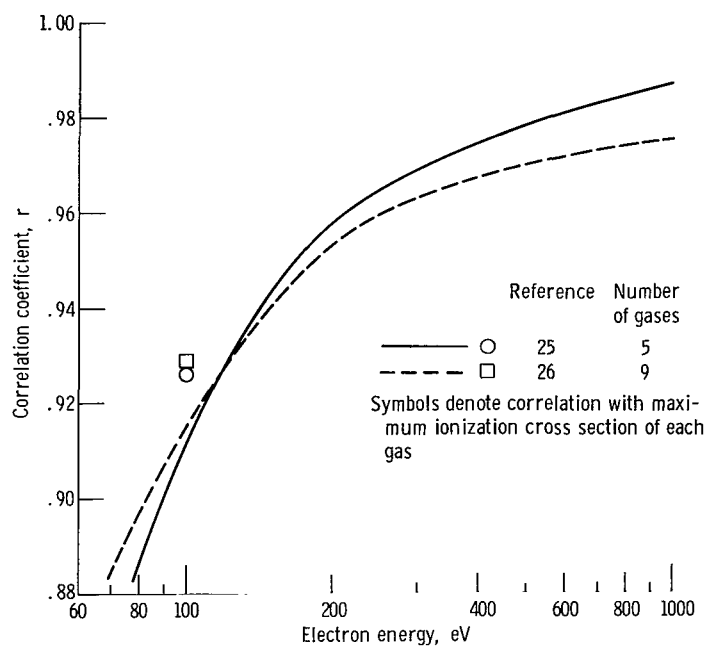
Figure 7. - Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for high-pressure ionization gages.

Figure 8. - Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for Alphatron gage.
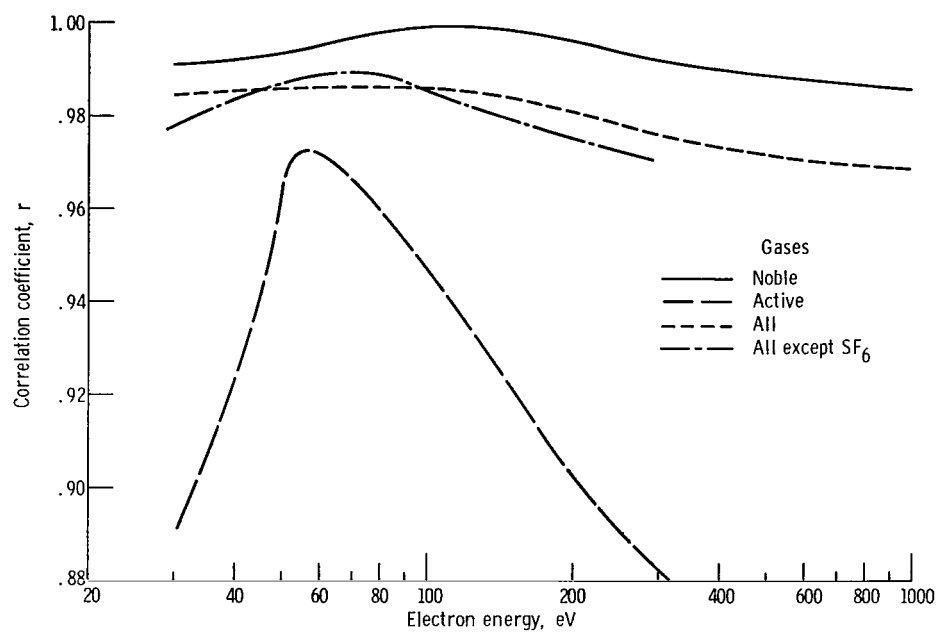
Figure 9. – Variation in coefficient of correlation of sensitivity with ionization cross section at various electron energies for gage W with different groups of gases.

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