

BRIEF REPORTS AND COMMENTS

This section is intended for the publication of (1) brief reports which do not require the formal structure of a regular article, and (2) comments on items previously published in the journal.

Bayard-Alpert ionization gauge sensitivity for C₇F₁₄

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Various empirical methods are applied to estimate the Bayard-Alpert ionization gauge relative sensitivity for C₇F₁₄. These values are compared to a measured value obtained by calibrating the ion gauge tube pressure sensor against a capacitance manometer. © 2008 American Vacuum Society. [DOI: 10.1116/1.2952455]

C₇F₁₄ (perfluoromethylcyclohexane) is a clear, colorless, odorless, stable liquid with a density of 1.78 g/cm³ and a vapor pressure of 107 Torr at 25 °C. It is used as an electrical insulator, chemical tracer, and fire-fighting substance. The C₇F₁₄ molecule has a relatively high cross section for low energy (<1 eV) electron attachment,¹ so that it can be used to produce plasmas with large concentrations of heavy (350 amu) C₇F₁₄⁻ negative ions, even at gas pressures <10⁻⁵ Torr.² Pressures in this range are measured with a Bayard-Alpert (BA) ionization gauge, but this requires a knowledge of the relative gas sensitivity factor. As no relative gas sensitivity factor for C₇F₁₄ was available, this article provides estimates of the gas sensitivity factor for C₇F₁₄ based on various methods that have been proposed.³⁻⁸ The estimated values are compared with a value obtained by calibrating a BA gauge against a capacitance manometer.

BA gauges are usually calibrated for N₂ and can be used with other gases (*X*) by applying the relative gauge sensitivity factor, $R(X) = S(X)/S(N_2)$, provided by the manufacturer. The estimated true pressure $P(X)$ is then obtained using $P(X) = P_{in}(X)/R(X)$, where $P_{in}(X)$ is the pressure indicated on the gauge controller. The sensitivity factor reflects the difference in ionization probability of the specific gas (*X*) relative to that for nitrogen. A number of empirical methods have been proposed for computing the gas sensitivity factors for various gas species. These methods attempt to determine which molecular property of the gas correlates best with available gas sensitivity data. Flaim and Ownby³ showed that there was a linear relation between the number of electrons per gas-phase molecule and the relative gauge sensitivity. Young⁴ discussed the application of the Flaim and Ownby method for hydrocarbon gases. Hollanda⁵ in an extensive study concluded that the molecular property that best correlated with relative gauge sensitivity was the ionization cross section. Nakao⁶ further investigated the ionization gauge sensitivity for many inorganic gases and hydrocarbon gases up to C₁₀ compounds and found a linear relationship between

the gauge sensitivity and the ionization cross section at an electron energy of 75 eV. Bartmess and Georgiadis⁷ (see also Schulte *et al.*⁸) also found good correlation with the total ionization cross sections at 75 eV but concluded that the best correlation was with the polarizability of the molecule. Unfortunately, measured polarizabilities of some fluorocarbons, such as C₇F₁₄, are not available. We applied these methods to obtain estimates of the relative gauge sensitivity factor, $S(C_7F_{14})/S(N_2)$, for C₇F₁₄ and compared these estimates to a value obtained by calibrating a BA gauge with the absolute pressure measured with a capacitance manometer.

Flaim and Ownby³ (FO) showed that if one plots the relative gas sensitivity versus the quantity $N_e/14$, where N_e is the number of electrons per molecule, a linear relation is obtained. If we extrapolate their plot for C₇F₁₄ with $N_e=168$, $N_e/14=12$, we obtain $[S(C_7F_{14})/S(N_2)]_{FO} \cong 7$. To apply the methods of Holanda⁵ and Nakao,⁶ values of the electron impact ionization cross sections $\sigma_i(E_e)$, where E_e is the electron energy, are needed. Ionization cross sections for N₂ were taken from the standard reference of Rapp and Englander-Golden,⁹ while those for C₇F₁₄ were taken from Asundi and Craggs.¹⁰ The Nakao⁶ method uses ionization cross sections at $E_e=75$ eV, and we find

$$\left[\frac{S(C_7F_{14})}{S(N_2)} \right]_{Nakao} = \frac{\sigma_{i,C_7F_{14}}(75 \text{ eV})}{\sigma_{i,N_2}(75 \text{ eV})} = \frac{16.5 \times 10^{-16} \text{ cm}^2}{2.39 \times 10^{-16} \text{ cm}^2} = 6.9,$$

in good agreement with the estimate based on the FO method. For comparison, relative gas sensitivity factors estimated using the methods discussed here for C₇F₁₄ and for a few other molecules are given in Table I, along with the values that were available in the gas sensitivity tables.¹¹

A measurement of the relative gas sensitivity factor for C₇F₁₄ was obtained by calibrating a BA ion gauge (Varian 571) against a capacitance manometer (MKS Baratron 627B). Both pressure gauges were deployed on a 2.5 l cylindrical, stainless-steel vacuum vessel, which was evacuated to a background pressure of $\sim 1 \times 10^{-6}$ Torr using a 160 l/s

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TABLE I. Relative BA ion gauge gas sensitivities.

Method or Source	Footnote	Molecule			
		C ₇ F ₁₄	SF ₆	CH ₄	CCl ₂ F ₂
Ionization cross sections	^a	6.9	2.4	1.6	3.8
Electrons per molecule	^b	7.0	3.2	1.1	2.8
Polarizability	^c	6.5–7.5	3.5	1.6	4.3
Gas sensitivity tables	^d	...	2.4	1.5	3.4
Capacitance manometer		6.4	2.3

^aReferences 6 and 7. N₂, SF₆, and CH₄ ionization cross sections in Ref. 9. C₇F₁₄ ionization cross sections in Ref. 10. CCl₂F₂ ionization cross sections in Ref. 12.

^bReferences 3 and 4.

^cReferences 7 and 8. Polarizabilities found in Ref. 13; C₇F₁₄ polarizability, see Ref. 14.

^dReference 11.

diffusion pump. A flask containing the C₇F₁₄ liquid was first pumped out using a mechanical pump to remove absorbed gases; then the C₇F₁₄ vapor was leaked into the vacuum system using a fine needle valve. A plot of the actual C₇F₁₄ pressure $P(\text{C}_7\text{F}_{14})$ measured on the capacitance manometer versus the indicated pressure on the ion gauge is shown in Fig. 1. By fitting a linear relation to the data, we obtain $P(\text{C}_7\text{F}_{14}) = P_{\text{in}}(\text{C}_7\text{F}_{14})/6.3$. As a check on the accuracy of this calibration, we repeated the procedure using SF₆ for which the relative gauge sensitivity is known. The SF₆ data are shown in Fig. 2, with a linear fit yielding $P(\text{SF}_6) = P_{\text{in}}(\text{SF}_6)/2.3$, in good agreement with the published values. The results of this calibration are summarized in the last line entry in Table I.

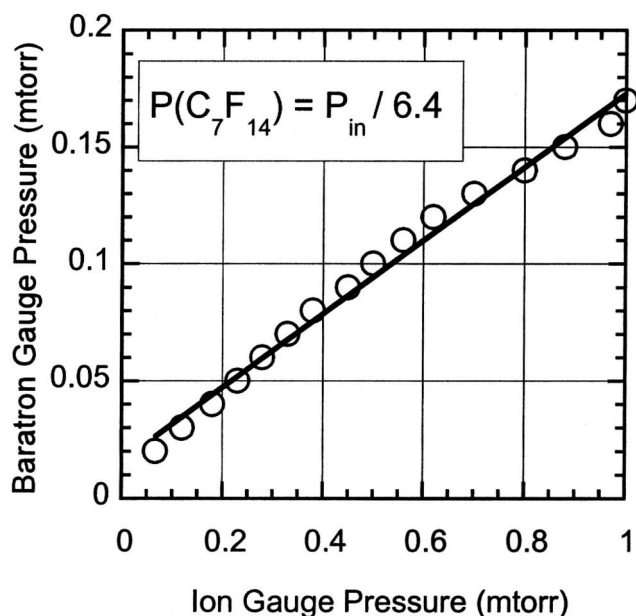


FIG. 1. C₇F₁₄ pressure measured with the Baratron capacitance manometer vs pressure indicated on the BA ion gauge.

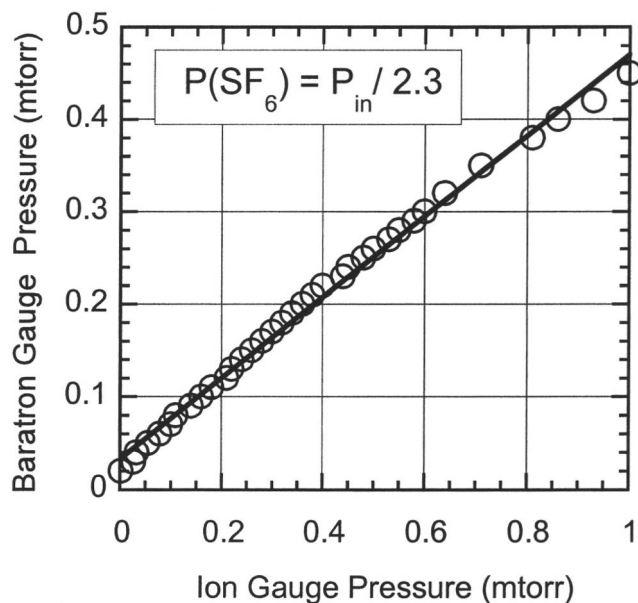


FIG. 2. SF₆ pressure measured with the Baratron capacitance manometer vs pressure indicated on the BA ion gauge.

Inspection of the results in Table I seems to indicate that the best correlation with gauge sensitivities, for the species studied, is obtained from the ratio of the ionization cross sections. We caution the reader that these gauge sensitivity factors only work over the central linear decades of the range of the ionization gauge being used since the sensitivity roll-over for the higher decades above 10⁻³ Torr varies with gas type. Finally, we stress in closing that it is well known that significant shifts in gauge tube sensitivity may occur over time and from one tube to another. These and other issues relating to the reliability of high vacuum measurements are discussed by Tilford.¹⁵

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