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Abstract

The ultrahigh vacuum requirements of ISABELLE is obtained by distributed pumping stations. Each pumping station consists of 1000 ℓ/s titanium sublimation pump for active gases (N_2, H_2, O_2, CO, etc.), and a 20 ℓ/s sputter ion pump for inert gases (methane, noble gases like He, etc.). The combination of the alarming production rate of methane from titanium sublimation pumps (TSP) and the decreasing pumping speed of sputter ion pumps (SIP) in the ultrahigh vacuum region (UHV) leads us to investigate this problem. In this paper, we first describe the essential physics and chemistry of the SIP in a very clean condition, followed by a discussion of our measuring techniques. Finally we present our measured methane, argon and helium pumping speeds for three different ion pumps in the range of 10^{-6} to 10^{-11} Torr. The virtues of the best pump are also discussed.

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I. Introduction

The Ultrahigh vacuum required in ISABELLE is obtained by distributed pumping stations. Each pumping station consists of a 1000 ℓ/s titanium sublimation pump for active gases (N_2, H_2, O_2, CO, etc.), and a 20 ℓ/s sputter ion pump for inert gases (methane, noble gases like He, etc.). The combination of the alarming production rate of methane from titanium sublimation pumps (TSP) and decreasing pumping speed of sputter ion pumps (SIP) in the ultrahigh vacuum region (UHV) leads up to investigate this problem. It is crucially important to know SIP pumping speeds for methane, argon, and helium under UHV conditions to ensure the successful operation of the accelerator.

In this paper, we first describe the essential physics and chemistry of the SIP in a very clean condition, with the survey of present understanding of the Penning discharge. The experimental results and discussion follow. The comparison of various SIP's from different manufacturers is presented.

II. Physics and Chemistry of Sputter Ion Pumps

The basic structure of the SIP is a Penning Cell with gettering material as a cathode, (see Fig. 1). Primary electrons, which are either produced from external excitation of free electrons in the metalic surface, or from field ionization of gas molecules, or secondary electrons produced by cosmic rays, will follow modified cycloidal orbits in the strong crossed electric and magnetic fields provided by the pump. When the primary electron collides with the gas molecule, it will either ionize the gas molecule and produce the secondary electron and ion or just follow its cycloidal path. The degree of ionization will depend on the ionization cross

section of that gas and the energy of the primary electron. The production of secondary electrons provides the mechanism for the Townsend avalanche. The electron which suffers energy loss due to inelastic collision will move its cycloidal orbit closer to the anode to regain its energy. Ions, produced from ionization, due to their mass have a much shorter transient time in the Penning structure than electrons in a stable discharge condition. The ion, driven by the strong electric field in the pump, will bombard the cathode and sputter the getter material out of the cathode and/or bury itself into the cathode. The sputtering provides both the secondary electrons for maintaining the constant population of electrons in the electron cloud and the gettering material. This getter material will either coprecipitate with gas molecules or react chemically with them to produce low vapor pressure compounds such as TiN, etc. The principal feature of SIP's in UHV condition is fairly simple. The great difference in transient time between ions and electrons in the Penning Cell results in a negative space charge. This trapped electron cloud maintained by Townsend avalanche criteria, sweeps out the space at the rate of the order of 100 MHz[1], in a manner analogous to the rotor of a mechanical forepump, disposing of molecules by ionization. The ions produced by this rotating electron cloud are driven by high voltage to the cathode to produce gettering material which in turn pumps gas molecules.

After Penning utilized the discovery of the Penning discharge by Phillips in 1898 to construct an ionization gauge, the stability of the discharge has beed studied. Only in 1958 the relevant theory was developed by Redhead[2]. Later we will use his approximate theory of striking characteristics as our guide to choose a suitable SIP for ISA

vacuum. Helmer and Jepsen[1] performed experiments to investigate his theory. They afforded a better understanding of Penning discharge in the low magnetic field region and established the basic idea of discharge stability.

A much more general description was proposed by Schuurman[3] in 1967. He classified all the discharge modes according to their magnetic field and pressure while anode voltage was held constant (see Fig. 2). As shown in figure 2 at constant B, one can traverse the modes of increasing gas density n_o (or the pressure P). At a very low pressure or small B the discharge is not self-sustaining. The variation of the potential along a path from the center to the anode can be seen in Fig. 2a. When the discharge is self-sustaining, different behavior is observed at low and at high B. At low B the space charge consists of electrons which can not rapidly cross the magnetic field to the anode. Ions formed within the discharge move more freely to the cathodes along the magnetic field. At high B, ignition of the discharge causes the potential on the axis to drop and the discharge enters the HMF region. Figure 2c shows a field-free plasma region which appears around the axis of the discharge. The electron cloud becomes a sheath adjacent to the anode. Dow's[4] experiment shows that there is a transition mode (TM) before the high-pressure (HP) mode. In HP the anode potential fall disappears abruptly which results in a normal glow discharge[5]. Finally, at the highest pressure the electron mean free path has become smaller than the cell dimensions, and the magnetic field is no longer essential for discharge to be self-sustaining (see region ϕ and

Fig. 2d). At high current this discharge may change into arc.

In the ISABELLE operating pressure region, there is no new theory describing it, except the Redhead theory of striking characteristics. Our experimental results seem to indicate its validity.

III. Experimental Result

In ISABELLE we use SIP's primarily to pump the small quantity of non getterable gases either left over from a 24 hour bake-out at 300°C or resulting from surface outgassing (via surface chemical reaction or diffusion from the bulk). To study the inert gas pumping behavior, we measure the pumping speed of SIP's at various pressures. At the same time we monitor the residual gas in the main chamber where the SIP is located. The initial pressure of 2×10^{-11} Torr (N_2 equivalent) is achieved by the combination of the TSP with the SIP under study. A cryopump with known conductance is used as a reference pump because its pumping speed is independent of pressure. It can not be over-emphasized how much the previous history of the SIP will influence its pumping behavior. Fortunately in the lifetime of ISABELLE under its normal operation, the SIP will not be subject to any pressure larger than 10^{-6} Torr while in operation. Understanding these conditions, we study either a brand-new pump directly from the factory or a carefully reconditioned pump. Because of the neglibible sticking probability of CH_4, He, and Ar on the titanium filament, the TSP contributes no pumping speed for these gases. Figure 3 shows the schematic diagram of the experimental set-up. We used the known conductance C and the

pressure measurement across the conductance to evaluate the pumping speed S

$$S = C\left(\frac{P_1}{P_2} - 1\right) \tag{1}$$

where P_2 is the partial pressure of the gas introduced to the main chamber and P_1 the residual pressure in the inlet chamber. The system we use cannot accurately measure the pumping speed of active gases such as N_2, because of their huge TSP pumping speed. In spite of our inability to measure the pumping speed of active gas, we succeeded in evaluating the pumping speed of an ISABELLE pumping station for various SIP candidates. Table I shows the results of this study including some parameters which affect the performance of the pump.

Figure 4 shows the results of pumping speed vs. pressure for three different pumps. The outstanding pumping speed of the Varian Diode in UHV region is clearly shown in the Figure. The physics behind this superiority is discussed in the discussion section.

IV. Discussion

Based on the theory proposed by Redhead[2)], there are two critical parameters which determine the stability of the discharge. These are the minimum requirements on the product of magnetic field and Penning Cell radius, $B\ r_a$, and striking voltage, V_s. They both have an inverse logarithmic dependence on pressure according to

$$B\ r_a\ (\text{minimum}) = a_1 \log \frac{b_1}{p} \tag{2}$$

$$V_s = a_2 \log \frac{b_2}{p} \tag{3}$$

in stable discharge condition where a and b are constants. This pressure dependence is intimately related to the detailed mechanism of Townsend Avalanche. The result implies that as the pressure decreases the SIP requires:

1. a higher magnetic field or larger diameter of the Penning Cell and,
2. a higher voltage to obtain a stable discharge. Six kilovolts is ample to initiate the strike. The strong correlation of the Penning Cell's diameter with pumping behavior in UHV region indicates the validity of equation (2). We believe this cannot be a simple coincidence, but actually describes the physics behind the pumping behavior in UHV condition. Of course, the quantitative prediction of pumping speed for various gases requires more than the stability criteria. One needs to include both physics and chemistry of pumping action to achieve this goal.

TABLE I. PUMPING SPEED OF SPUTTER ION PUMPS

	ULTEK			VARIAN TRIODE			VARIAN DIODE		
Radius of Anode	1/4"			25/64"			5/8"		
Length of Anode	9/16"			1"			1½"		
Gap between Electrodes	7/32"			3/16"			1/2"		
Mag. Field	1.6K Gauss			1.3K Gauss			1.3K Gauss		
High Voltage	5200 Volts			5200 Volts			5200 Volts		
Pressure	Pumping Speed CH_4	Ar	He	Pumping Speed CH_4	Ar	He	Pumping Speed CH_4	Ar	He
5×10^{-11}	-		-	7.5ℓ/s	-	-	9.4ℓ/s	-	-
1×10^{-10}	6.0ℓ/s	3.3ℓ/s	-	9.3ℓ/s	5.4ℓ/s	-	10.5ℓ/s	8.1ℓ/s	-
5×10^{-10}	6.6ℓ/s	3.5ℓ/s	∿1 1ℓ/s	10.1ℓ/s	6.1ℓ/s	∿1 ℓ/s	11.3ℓ/s	8.7ℓ/s	2 ℓ/s
1×10^{9}	6.8ℓ/s	3.4ℓ/s	0.5ℓ/s	10.9ℓ/s	7.1ℓ/s	1.0ℓ/s	9.0ℓ/s	9.0ℓ/s	3.2ℓ/s
5×10^{-9}	7.0ℓ/s	3.7ℓ/s	0.2ℓ/s	11.6ℓ/s	7.9ℓ/s	3.0ℓ/s	12.5ℓ/s	9.1ℓ/s	7.9ℓ/s
1×10^{-8}	8.2ℓ/s	4.3ℓ/s	0.4ℓ/s	12.3ℓ/s	8.7ℓ/s	4.1ℓ/s	12.8ℓ/s	9.0ℓ/s	9.9ℓ/s
5×10^{-8}	9.7ℓ/s	4.2ℓ/s	2.3ℓ/s	12.9ℓ/s	9.1ℓ/s	5.2ℓ/s	12.9ℓ/s	8.7ℓ/s	11.0ℓ/s
1×10^{-7}	9.8ℓ/s	5.7ℓ/s	4.8ℓ/s	12.8ℓ/s	9.4ℓ/s	6.4ℓ/s	12.9ℓ/s	8.6ℓ/s	11.5ℓ/s
5×10^{-7}	9.7ℓ/s	5.9ℓ/s	5.9ℓ/s	-	9.5ℓ/s	7.4ℓ/s	12.8ℓ/s	-	-
1×10^{-6}	-	4.8ℓ/s	6.4ℓ/s	-	9,5ℓ/s	8.0ℓ/s	-	-	-

Figure Captions

Figure 1 Configuration of a Penning Cell

Figure 2 Survey of Penning Mode and Their Potential Profile

Figure 3 Sketch of Pumping Speed Test Stand

Figure 4 Pumping Speed vs. Pressure

References

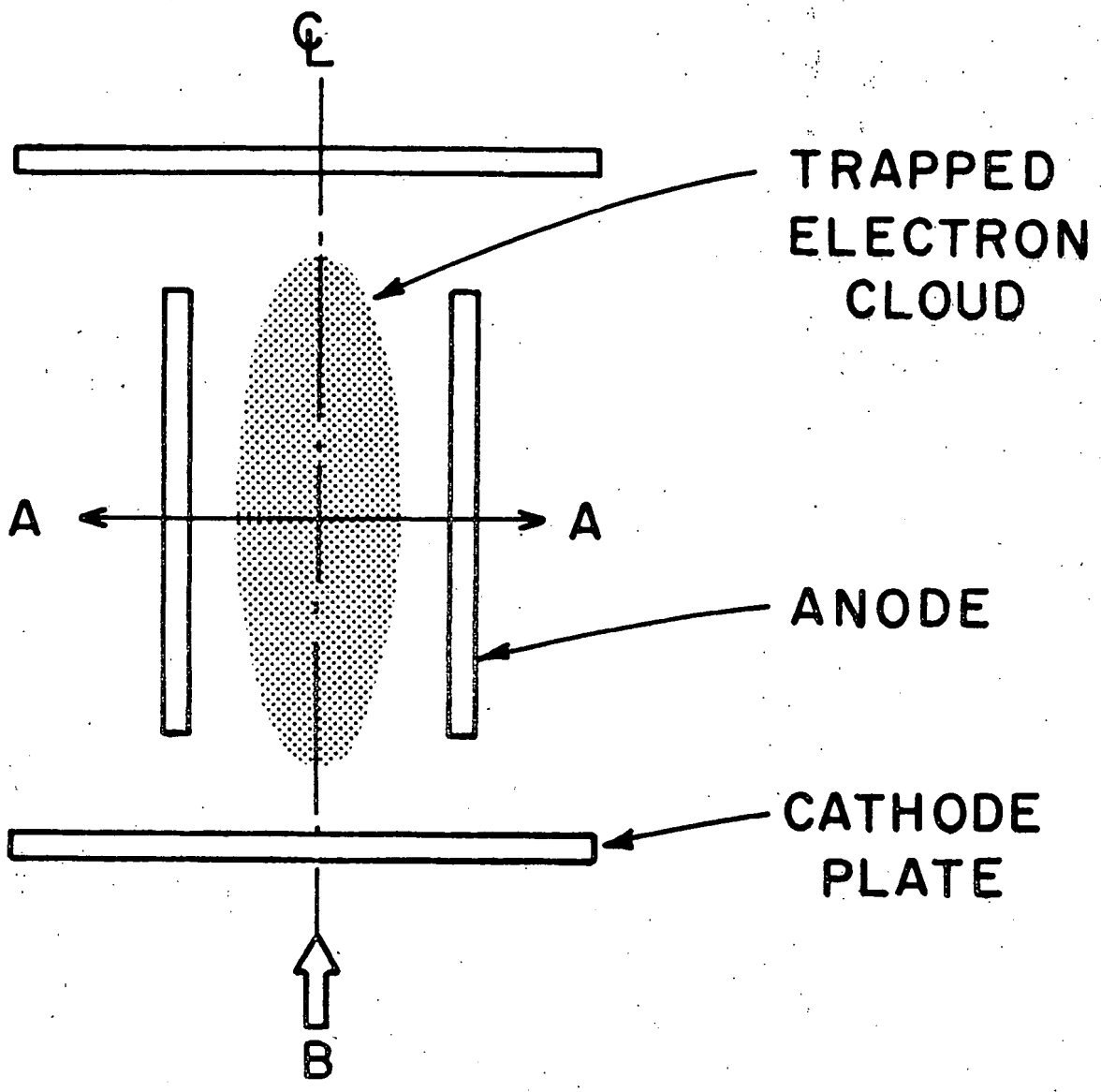
[1] J.C. Helmer and R.L. Jepsen, Proc. IRE. 49 (1961) 1920.

[2] P.A. Redhead, Canad, J. Phys., 36 (1958) 255.

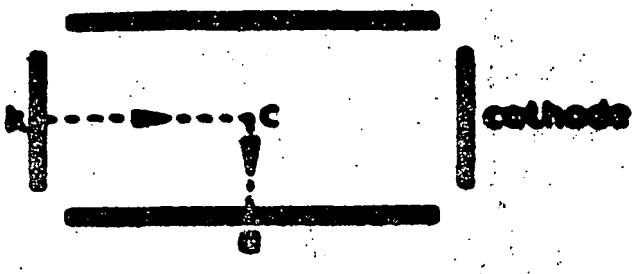
[3] W. Schuurman, Physica 36 (1967) 136.

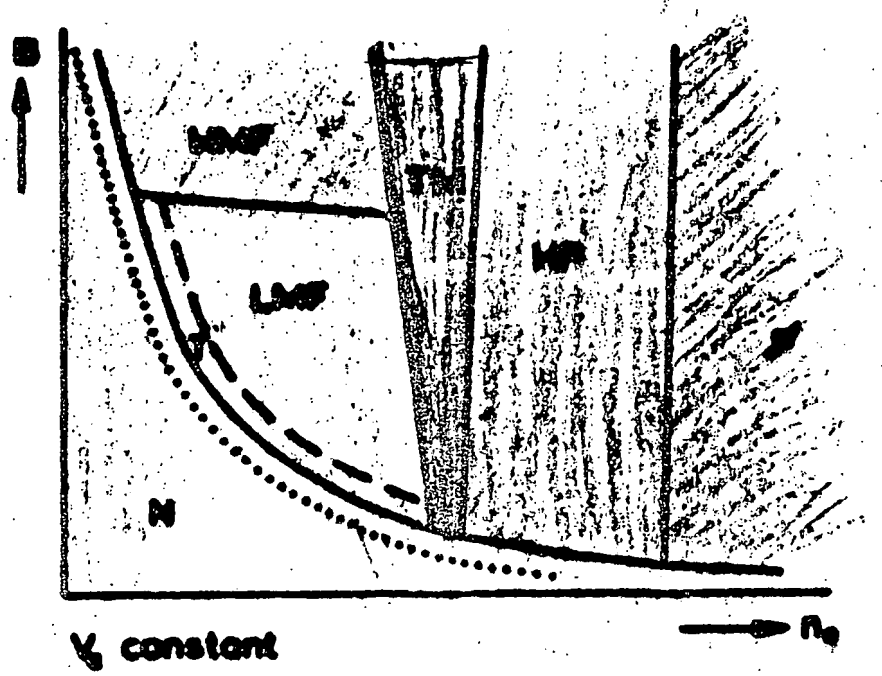
[4] D.G. Dow, J. Appl Phys. 34 (1963) 2395.

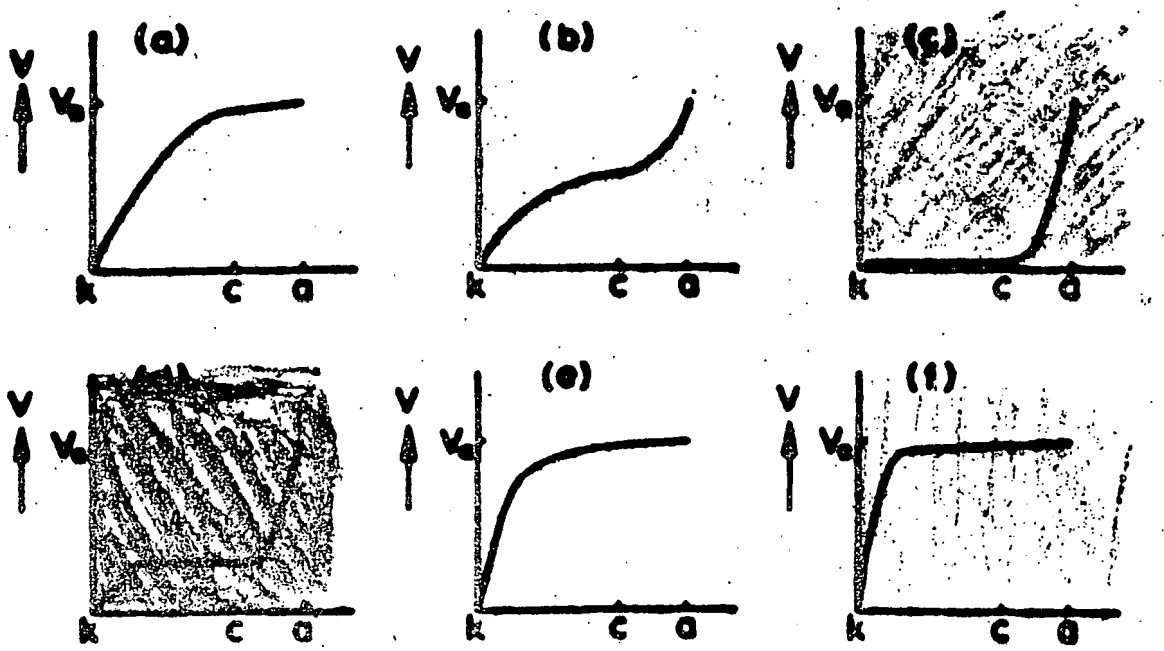
[5] F. Salz, e.a., Phys. Rev. Letters (1961) 523.

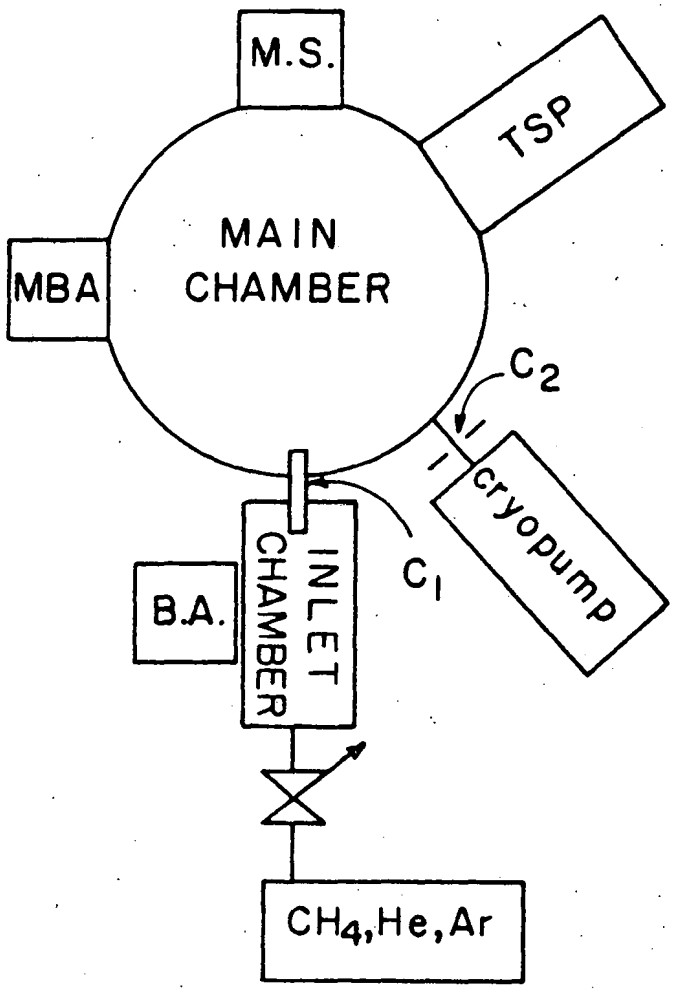


CONFIGURATION OF A PENNING DISCHARGE


k
c
a
cathode


B
NMF
LMF
HF
N
V_a constant
n_e


(a)
(b)
(c)
(e)
(f)
V
V_a
k
c
a



CAPTION: DIAGRAM OF PUMPING SPEED TEST STAND

C_1 is conductance of 0.1 L/S for CH_4, a capillary tube

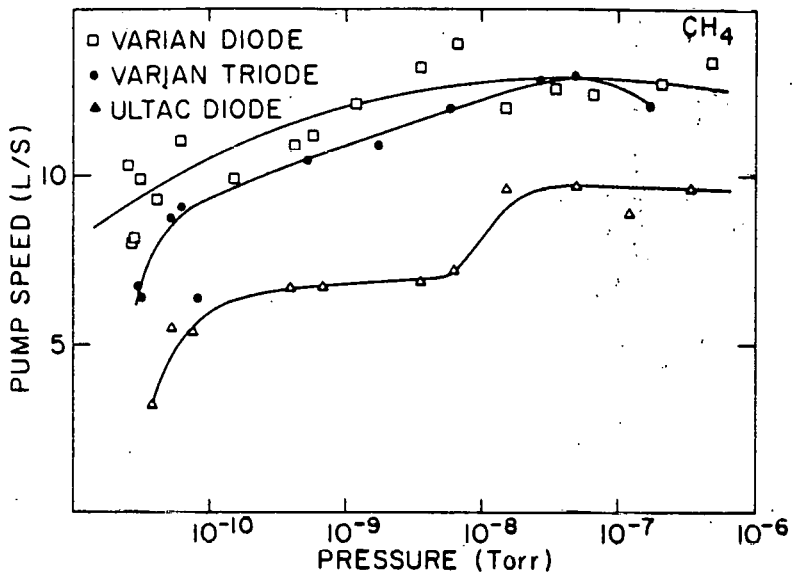
C_2 is conductance of an orifice

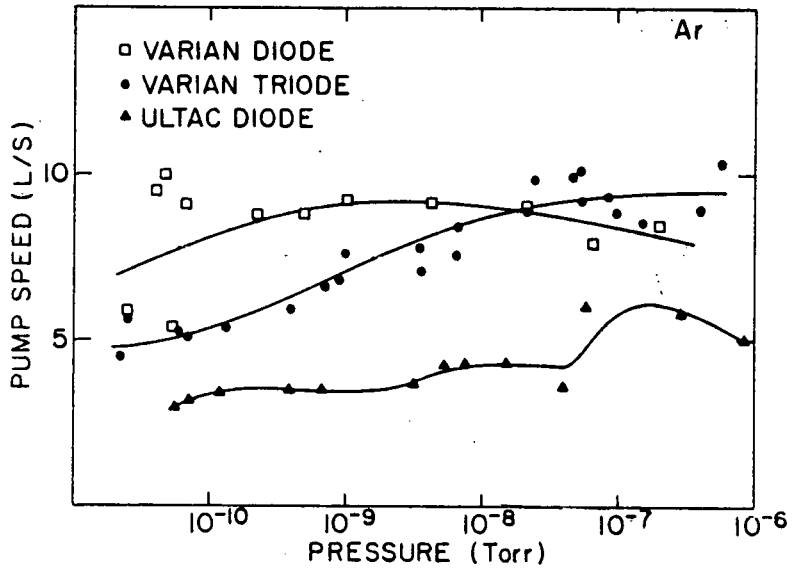
B.A. is a bare Bayer-Alper gauge

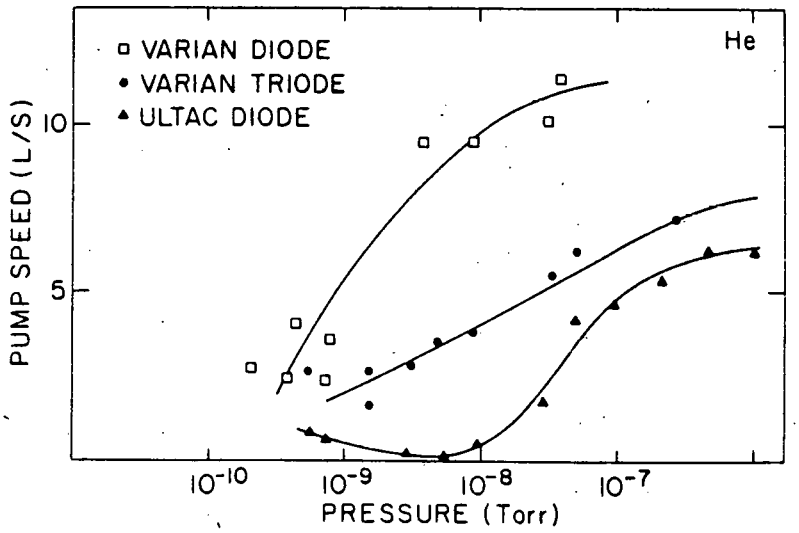
M.B.A. is a modulated Bayer-Alper gauge, Balzer IMR. 103

M.S. is a quadropole mass spectrometer, LH Q200

T.S.P. is a Titanium sublimator pump, varian


VARIAN DIODE
VARIAN TRIODE
ULTAC DIODE
CH4
PUMP SPEED (L/S)
10
5
10-10
10-9
10-8
10-7
10-6
PRESSURE (Torr)


VARIAN DIODE
VARIAN TRIODE
ULTAC DIODE
Ar
PUMP SPEED (L/S)
10
5
10-10
10-9
10-8
10-7
10-6
PRESSURE (Torr)


VARIAN DIODE
VARIAN TRIODE
ULTAC DIODE
He
PUMP SPEED (L/S)
10
5
10-10
10-9
10-8
10-7
PRESSURE (Torr)