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**VACUUM SEPARATION USING THIN CARBON FOILS**

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**ABSTRACT**

The vacuum conductances of thin carbon foils ( $5-20 \mu\text{g}/\text{cm}^2$ ) of comparatively large area ( $> 1 \text{ cm}^2$ ) were measured and the ratios between the conductances of the foils and their areas, that is the foil specific conductances, were computed. The values of the specific conductances of the tested foils were measured to be between  $10^{-2}$  and  $10^{-3}$  liters/(sec  $\text{cm}^2$ ). Such low values disclose the possibility of using thin carbon foils placed across a channel of large cross-section in order to separate two vessels in which notably different vacuum levels need to be maintained.

## 1. INTRODUCTION

We report results obtained while studying the possibility of maintaining two highly different vacuum levels in two vessels communicating through an aperture  $A$  of comparatively large area (several square centimeters) when the aperture is closed by an extremely thin ( $5 - 20 \mu\text{g}/\text{cm}^2$ ) carbon foil.

This study has been triggered by the following experimental problem. Antiprotons from the LEAR facility at CERN are injected into an anticyclotron [1] producing a bunch of  $10^8$  antiprotons with energy of few Kev confined in a volume of linear dimensions of few centimeters. At this stage we need to transfer the antiproton bunch from the anticyclotron vacuum chamber, which is at a pressure not lower than  $10^{-3}$  mbar [2], to a trapping and storing device [3] kept at a very good vacuum ( $< 10^{-11}$  mbar) where the antiprotons can live for long periods of time (hours) [4].

Our problem can then be summarized as follows: we have two different vessels (1 and 2), the first maintained at a comparatively high pressure  $p_1$ , the second evacuated by an high quality pumping system (characterized by a pumping speed  $S_2$  and by a limit pressure  $p_2^l$ ) in which we need to have a very good vacuum. The two vessels are to be connected by a channel (a conductance  $C$  from the vacuum point of view) having a cross-section of many square centimeters to allow the antiprotons to go from one vessel to the other. Owing to the large required channel cross-section, the differential pumping technique is absolutely inadequate; by separating the two vessels using carbon foils we may provide a good vacuum separation and still allow antiprotons of the given energy (about 10 or 15 Kev) to pass through.

In principle the theoretical conductance  $C_t$  of an ideally homogeneous foil, particularly if very thin, should depend only upon the diffusion process, and should be very small. A real membrane has a conductance  $C$  much higher than  $C_t$  and presumably its value depends upon inhomogeneities, principally upon the number and the dimensions of very small holes that eventually cross the membrane material.

Owing to the finite value of the membrane conductance  $C$ , there is then a flux  $\phi$  of gas from vessel 1, at a pressure  $p_1$  that we suppose to be constant, to vessel 2 at a pressure  $p_2$ . Since  $p_1 \gg p_2$  we can write

$$\phi = C(p_1 - p_2) \simeq Cp_1. \quad (1)$$

This flux must be added to the flux generated by the degassing of the walls of vessel 2. If we also assume that  $C$  is much less than the pumping speed in vessels 1 and 2 the final pressure in vessel 2 will be given by

$$p_2 \simeq p_2^l + \frac{D + \phi}{S_2} = p_2^* + \frac{C}{S_2} p_1 \quad (2)$$

$D$  being the degassing rate in vessel 2 and  $p_2^* = p_2^l + D/S_2$  being the limit pressure obtainable in vessel 2 when the flux of gas from 1 to 2 is equal to zero.

## 2. EXPERIMENTAL SETUP

Carbon foils of various thickness are commercially available. The majority of our data were taken using foils of 5x7 cm produced by The Arizona Carbon Foil Company; we also tested smaller membranes produced by the Yssum Research Company (Israel).

The foils, evaporated from spectrographically pure graphite, are shipped on a glass support. The mounting process consists in slowly lowering the foil and its glass support into water; when the lower edge of the foil reaches the water the part of the foil which is in contact with the water separates from the glass substrate and remains at the surface of the water. At the end of the immersion process the entire foil freely floats on the water. At this stage it is possible to immerse a new support into the water and slowly transfer the foil on it while carefully raising the support. When the foil is completely dry it can be mounted in a vacuum apparatus. It is very difficult to mount foils on holes of large dimensions and handle them because the probability of a foil breaking largely increases with the increasing of the hole surface and also because the pressure difference that a foil of given thickness, covering a circular hole, can sustain varies inversely with the hole diameter [5] (though it varies from foil to foil). Typically a foil of  $10 \mu\text{g}/\text{cm}^{-2}$  covering an hole having an unsupported diameter of 5.9 mm can sustain a mean pressure difference of about 1 mb. This pressure difference directly increases with the foil surface density.

In order to test foils of large area we mounted them on two different supports: the first one, having a 0.37 transparence, was made by drilling 37 round holes of 2 mm. diameter into a 2 cm. diameter circular surface; the second, of transparence 0.69, was made by a matrix of square holes (2.5 mm.x 2.5 mm.) spaced 0.5 mm. one from the other, distributed on a 3 cm. diameter circular surface.

The conductances  $C$  of different foils were measured using the experimental apparatus shown in fig. 1. The apparatus, divided by the foil in the two distinct regions 1 and 2, is first evacuated using only pumps  $P_a$  and  $P_b$  while keeping valve  $V_4$  closed and valves  $V_1$ ,  $V_2$  and  $V_3$  opened. When a pressure around  $10^{-1}$  mb is reached,  $V_1$  and  $V_2$  are closed,  $V_4$  is opened and all the pumps shown in fig. 1 start to be used. When the final equilibrium pressures  $p_1^0$  and  $p_2^0$  are achieved their values are measured using gauges  $G_1$  and  $G_2$ . Then the needle valve  $V_0$  is used to inject a small and constant flux of gas  $F_g$  in chamber 1 and pressures  $p_1^g$  and  $p_2^g$  in the new equilibrium situation can finally be measured.

The equilibrium pressures  $p_2^0$  and  $p_1^0$ , without any external flux, satisfy the equilibrium relation

$$-S_2(p_2^0 - p_2^l) + C(p_1^0 - p_2^0) + D = 0 \quad (3)$$

A similar equation can be written for the equilibrium pressures  $p_2^g$  and  $p_1^g$  when a gas flux  $F_g$  is injected

$$-S_2(p_2^g - p_2^l) + C(p_1^g - p_2^g) + D = 0 \quad (4)$$

Taking  $D$  from equation (3) and substituting it in (4) we obtain a linear relation between  $p_1^g$  and  $p_2^g$  that does not depend on the value of  $F_g$

$$p_1^g - p_1^0 = \left(\frac{S_2}{C} + 1\right)(p_2^g - p_2^0) \simeq \frac{S_2}{C}(p_2^g - p_2^0) \quad (5)$$

Once the actual value of  $S_2$  for pump  $P_b^t$  is known, the foil conductance  $C$  can easily be measured taking data at different values of  $F_g$  and fitting the data in order to obtain the value of the constant  $S_2/C$ . Fig. 2 shows typical results obtained with hydrogen. Measurements with different kinds of gases have shown the expected dependence of  $C$  on the inverse square root of the gas mass number. The value of the specific conductance  $C_s$  (the value of  $C$  divided by the foil area) shows considerable variations for foils of the same thickness and does not depend substantially on the thickness of the foils within the range of our interest ( $5 - 20 \mu\text{gr}/\text{cm}^2$ ). Our measurements give values of  $C_s$  within the range  $10^{-2} - 10^{-3} \text{ l}/(\text{sec cm}^2)$ .

### 3. CONCLUSIONS

As anticipated, the conductance of our carbon foils seems to be due almost entirely to the presence of small holes on their surfaces. This conclusion is the result of three observations:

- a) the large discrepancy between the values of the actually measured conductances and the order of magnitude of the theoretical values that can be computed using the diffusion coefficients of known materials;
- b) the large variations of the measured values and their practical independence of the membrane thickness;
- c) the direct observation of the foil surfaces by a metallographic microscope.

The actual conductances are low enough to allow to maintain a good vacuum separation between different vessels in many situations of practical interest.

Rewriting equation (2) as

$$\frac{p_2}{p_1} = \frac{p_2^*}{p_1} + \frac{C}{S_2} \quad (6)$$

it is easily seen that the ratio  $p_2/p_1$  (if its absolute limiting value  $p_2^*/p_1$  is low enough) is directly given by the ratio  $C/S_2$ . Therefore in a typical situation where  $S_2 = 500 \text{ l}/\text{sec}$  and where vessel 2 communicates with vessel 1 through an aperture having an area of about  $10 \text{ cm}^2$ , the ratio  $p_2/p_1$  takes a quite high value of about  $10^{-4}$ .

Obviously if higher ratios are needed, a series of two or more foils can be used, which is exactly what we plan to do in the particular situation mentioned in the introduction of this paper in which a vacuum separation of about  $10^{-8} - 10^{-7}$  is required.

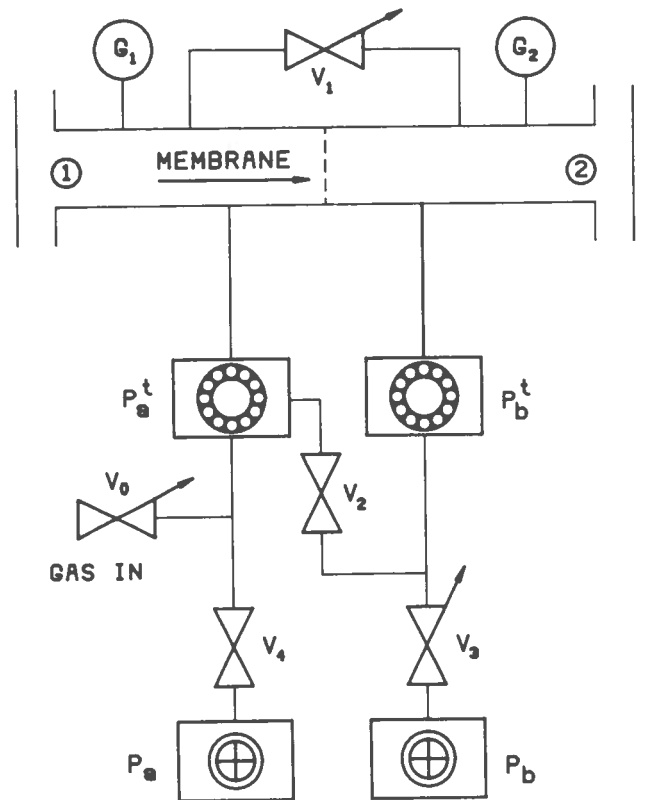


Figure 1 Scheme of the apparatus used to measure the foil conductances.

$P_a$  and  $P_b$  are rotary pumps and  $P_a^t$  (80 l/sec) and  $P_b^t$  (100 l/sec) are turbomolecular pumps;  $G_1$  and  $G_2$  are vacuum gauges.

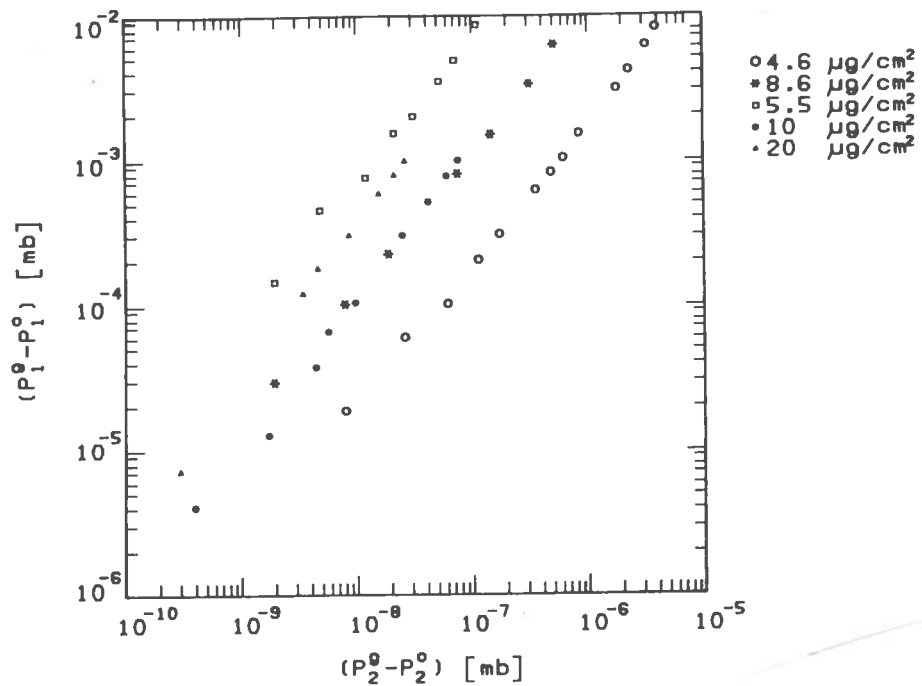


Figure 2 Behaviour of the pressures in our apparatus when a gas flux of hydrogen is injected.