4.2 Vacuum Pumping by Freezing Molecules

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For the ISR intersections, where the p–p collisions take place, a pressure lower than 10^{-10} Pa[b] was required to minimize the disturbing proton–gas interactions. This pressure range corresponds to a molecular density of 10^3 to 10^4 molecules per cm^3. At the time of the ISR project proposal, condensation cryopumping was thought to be the only way to achieve this goal. This technique is based on the condensation of the residual gas molecules onto a metal surface having a temperature at which the vapour pressures (VP) are below the desired level.

At the boiling temperature of liquid helium (4.2 K) all condensable gases display VPs lower than 10^{-11} Pa, with the exception of hydrogen, H_2, for which it is higher by many orders of magnitude. However, by extrapolating its VP curve, a sufficiently low H_2 pressure should be within reach at 2 K. In order to verify experimentally the validity of this extrapolation, the equilibrium pressure of condensed H_2 was investigated. The initial results were surprising: below about 3 K this pressure departed from the VP curve, showing an irreducible limitation in the $10^{-7}/10^{-8}$ Pa range, no matter how low the condensation temperature. Further studies showed that this limit is proportional to the room temperature radiation absorbed on the metal surface where condensation occurs [12].

Phonons, the quanta of the atom's energy in a solid, are produced in the metal substrate by the absorbed radiation. It was natural to assume that these phonons could induce molecular desorption when reaching the surface of the condensed H_2. For this to be possible, they should cross the H_2 layer. Hydrogen is very particular in this respect; it is the only solidified gas able to transmit phonons of energy in excess of what is needed to desorb a molecule. A spectacular confirmation of this mechanism was obtained by interposing below the condensed H_2 a thin layer of another gas (e.g. N_2 or Ar) which could inhibit the transmission of the energetic, disturbing phonons. The interposed gas layer produced the expected effect and the H_2 pressure limit was decreased to below 10^{-10} Pa [12].

It would obviously be strange to inject heavy gases in an ultra-high vacuum system to improve the pumping of H_2, but fortunately a more reasonable alternative exists. The disturbing energetic phonons are produced by the thermal radiation from room temperature surfaces, so if the condensing surface is well protected by a low temperature shield, desorption can be decreased. In the CERN design (Fig. 4.4, left), only 5×10^{-4} of the radiation impinging on the shield

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[b]The pascal, Pa, one N/m^2, is the official unit of pressure. It replaced the Torr, which is 133 Pa.

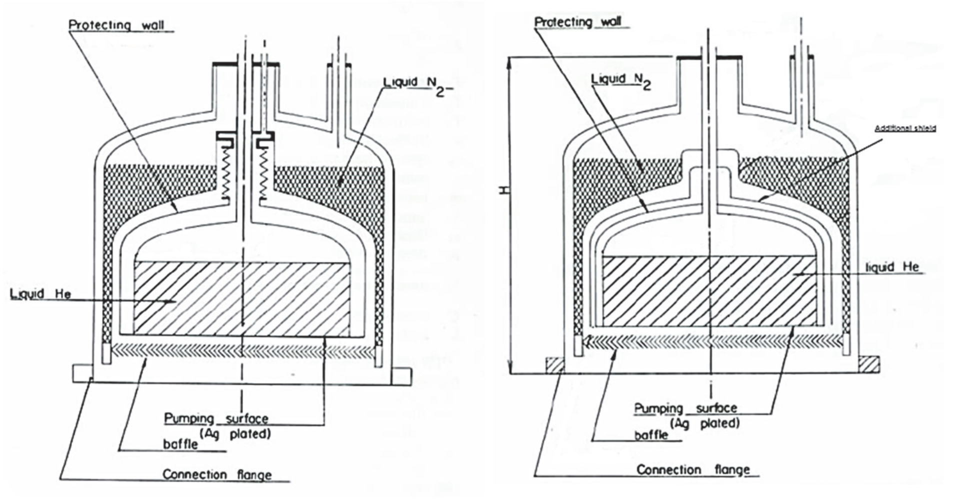

Fig. 4.4. (Left) first model — the function of the protecting wall is to avoid gas release due to the variation of He level. The double wall volume is under vacuum [13]. (Right) improved model — the double wall volume is filled with Ne, which provides good thermal contact during the initial cooling and thermal insulation at 4.2 K [14].

(a baffle cooled with liquid N_2) is transmitted to the condensation surface, resulting in a H_2 radiation induced pressure below 10^{-10} Pa [12]. The improved shield also led to a welcome reduction in the consumption of liquid helium.

One of the ISR experimental areas (point 6) was equipped with two large cryopumps, where a pressure lower than 10^{-10} Pa was achieved.

The initial model [13] was later improved by introducing an additional shield cooled by the evaporating He (Fig. 4.3, right). The liquid He consumption was then so low that it was possible to operate 200 days without refilling the 11 litre vessel [14]. The improved model was later used for the H_2 jet target experiment at ISR point 8, and for the Viksi cyclotron at the Hahn Meitner Institute in Berlin.

Cryopumping provides the advantages of a very high pumping speed and low ultimate pressure. On this ground it was considered the best pumping technique for about 10 years, at the end of the 1970s. But the advent of commercial large turbomolecular pumps and the use of Getter pumping (in the form of either Titanium sublimation or Non Evaporable Getters (NEG)) to produce extremely low pressures reduced the interest for this technique, which suffers the complication of having to provide and handle liquid helium.

Besides being a facility for physics research, the ISR was also a test bench for solutions which could be later adopted for a larger accelerator equipped with superconducting magnets. In these magnets the vacuum chamber would be cold and its behaviour with respect to the ISR pressure instabilities would be different.

To evaluate such "cold bore" behaviour, a cryostat containing a 1.3 m long vacuum chamber cooled at temperatures from 2 K to 200 K was installed in the ISR. Various quantities of different gases were condensed on the chamber surfaces while beams up to 40 A were circulating [15]. The vacuum was found to remain stable even in the most severe conditions thanks to the large pumping speed provided by cryopumping.

These positive results and the solid experience gained provided the confidence to propose cryopumping on a large scale in LHC where it is now used successfully in the cold sectors stretching over about 18 km (Chapter 8).

4.3 How to Measure Almost Nothing

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In the technology of Ultra High Vacuum, pressure is usually measured by means of ionization gauges. In such gauges the electrons emitted by a hot filament (cathode) are accelerated by the positive potential of a grid (anode) and ionise the residual gas molecules, which are then collected by a third electrode, the ion collector. The current reaching the collector is proportional to the pressure. However, at low pressure, the performance of this gauge is limited due to X-rays produced by electrons striking the grid. This radiation extracts electrons from the ion collector resulting in a current (I_x) that falsifies the result.

A major improvement was achieved by Alpert in 1950 who replaced the ion collector surrounding the grid with a thin wire at its centre (Fig. 4.5a). The large reduction of the collector area resulted in a decrease of I_x, and the low pressure limit of the gauge (called the Bayard-Alpert gauge, B.A.) was reduced by a few orders of magnitude, down to the 10^{-9} Pa range. Alpert himself remarked a few years later that it might not be possible to reduce I_x indefinitely by reducing the collector diameter because "there may be a critical size below which the probability of collecting ions reduces as rapidly as does the X-ray effect" [16]. This was because the tangential component of the velocity of the ions inside the grid would prevent a fraction of them from reaching the collector when first approaching it, and — assuming the electric field inside the grid to be perfectly radial — they would never be collected. Decreasing the collector diameter below about 0.1 mm would decrease I_x, but the ion current would also decrease in the same proportion and the performance of the gauge would not improve. This was confirmed by theoretical calculations and some experiments, and became vacuum technology dogma.