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AN IN-SITU GLOW DISCHARGE CLEANING METHOD FOR THE LEP VACUUM SYSTEM

by

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1. Introduction

In an electron-positron storage ring like LEP, one of the parameters which limits the lifetime of the stored beams is the average pressure in the vacuum system. In LEP¹⁾ a beam-gas bremsstrahlung lifetime of 20 h is required which implies a sufficiently low pressure. A special phenomenon making it difficult to achieve this goal, is gas desorption by synchrotron radiation. This radiation with a power of up to a few kW/m is emitted by the circulating beam in the arcs of the machine.

As it is generally accepted that at least the major part of the radiation induced gas desorption is by photoelectrons, we will use the coefficient of electron induced desorption (molecules/electron) to measure the efficiency of a cleaning method. A final test with actual synchrotron radiation would, of course, be an advantage.

Any cleaning method worth applying should fulfil several requirements. First it must reduce the electron induced desorption yield substantially, i.e. by a few orders of magnitude - and all along the internal surface of the vacuum system. The reduction in desorption yield must not deteriorate over a long time with or without beam. Finally it should be free of detrimental effects like destruction of gauges, pick-ups and other special equipment or loading of the vacuum system with gases which are difficult to pump such as rare gases. Applied to an in situ glow discharge method, this means that the discharge has to bombard all the internal surface of a chamber, i.e. has to extend all along a chamber. In addition, special equipment in the vacuum system has to be designed such that it can withstand the glow discharge or it is protected against the discharge.

Glow discharge cleaning methods either prior to installation or in situ have been proposed and applied to several other installations with critical vacuum requirements. In the intersecting storage rings at CERN, Geneva, a discharge method using an Ar-O₂ mixture²⁾ prior to installation has cured a performance limiting vacuum problem due to ion induced desorption. The vacuum chambers of the PETRA e⁺e⁻ storage ring have been treated by Argon discharge prior to installation. The proposed in situ method³⁾ has never been applied. In situ glow discharge has been proposed for the Japanese electron storage ring projects⁴⁾. For fusion devices in situ discharge cleaning is actually a widely applied method (see for example ref. 5). Edwards⁶⁾ shows that glow discharge creates in addition to substantially reducing the desorption yield, a 'wall pumping speed' for CO and CO₂.

There are other different methods for dealing with desorption problems. Besides installation of very high pumping speeds or bakeout^{7,8)}, encouraging results have been obtained by cleaning with atomic hydrogen created by a hot tungsten filament⁵⁾ or by electron bombardment (see for example refs. 3 and 8). At present, e^+e^- storage rings are normally cleaned by the synchrotron light itself ('beam cleaning') which implies the running of the machine for extended periods of time (which does not exclude machine development work).

Nevertheless, glow discharge cleaning seems to offer some attractive features for a very large machine. It can be combined with bakeout at hardly any extra cost in time or money. There is no need to actually operate the machine and cleaning can proceed at the same pace as installation. An opened sector can be reconditioned to full performance in less than 3 days including pumpdown and a 12 or 24 hour bakeout. The required pumping speed in a cleaned system is modest. Provided there are some roughing ports to introduce the discharge gas and a linear pump structure which can serve as anode, there are no additional installations required in the vacuum system.

2. Experiments and Results

Three different points have been experimentally investigated. First the current density distribution of the discharge with various parameters, secondly the wall pumping speed for CO (by sticking of CO to discharge cleaned surfaces) and finally the desorption yields obtained.

2.1 Current density distribution:

Fig. 1 shows a sketch of the set-up used. It consists of a 7 m long aluminium test chamber, either a PETRA chamber or a LEP prototype chamber (profile see Fig. 1b), with a continuous flow of gas passing through (3 - 10 torr l/s). For running the discharge, the linear ion pump was used as an anode. The glow discharge had, therefore, to penetrate into the main channel through the pumping slots. The gas pressure during discharge is measured with a mechanical gauge with electric readout. Otherwise the pressure is measured by a Bayard-Alpert gauge. The gauges have been protected against the discharge by installing a wire mesh (~ 1.2 mm mesh size) across the opening of the side arm where the gauges are installed. Through a valve, situated at the downstream end of the test chamber, a small flow of gas was continuously extracted into a separately pumped mass spectrometer. Thus the gas composition could be monitored continuously. The current density distribution was observed via pick-up electrodes

situated every 25 cm along the chamber. Sixteen of these electrodes were connected to a desk top calculator to read the current density distribution automatically. Fig. 2 shows an example of the distributions obtained.

The experiments were performed in each of the two different test chambers, using helium, neon and argon. Current density distributions for various pressures between 0.1 and 4 torr and currents from 0.25 A upward have been recorded. The highest possible current was determined by instabilities which tend to transform the discharge into an arc above a certain current determined by the pressure and history of the chamber. Running the discharge for some time increased the highest possible current to a fairly stable value.

The current density distributions were classified into three categories:

- A The discharge covers the chamber all along the linear ion pump used as anode plus 60 cm without linear ion pump
- B The discharge covers the chamber all along the linear ion pumps
- C The discharge covers parts of the chamber.

Figs. 3 to 8 show the regions of distributions, type A, B and C for the different chambers and gases.

2.2 Wall pumping speed

The wall pumping speed for CO was measured by comparison with the conductance of the test chamber. We consider the differential equation

$$c \cdot \frac{d^2 p}{dx^2} - p \cdot S_w = 0 \quad (2.2.1)$$

describing the pressure rise p along a tube with a conductance c and a pumping speed S_w per unit length with a gas injection at one end where x is a coordinate along the test chamber (Fig. 1). The pump of pumping speed S on the downstream end ($x=L$) is taken into account by the border condition:

$$c \cdot \frac{dp}{dx} + p \cdot S = 0 \text{ for } x = L \quad (2.2.2)$$

the following solution can be found by standard methods (e.g. Ref. 18):

$$p(x) = p(L) \left\{ \cosh \left[\sqrt{\frac{S_w}{c}} (L - x) \right] + \frac{S}{\sqrt{S_w \cdot c}} \cdot \sinh \left[\sqrt{\frac{S_w}{c}} (L - x) \right] \right\} \quad (2.2.3)$$

For zero wall pumping speed S_w , expansion in a series yields

$$p(x) = p(L) \left[1 - \frac{S}{c} (L - x) \right] \quad (2.2.4)$$

in agreement with a more basic treatment of this special case.

In the actual system, the pressure could be measured at two points along the test chambers at $x = L$, the downstream end and at $x = 0.5 L$, the centre of the chamber. Let $p(L) = p_1$ and $p(L/2) = p_2$. Then equ. (2.2.3) can then be transformed to

$$\frac{p_2}{p_1} = \cosh \left(\sqrt{\frac{S_w}{c}} \cdot \frac{L}{2} \right) + \frac{S}{\sqrt{S_w \cdot c}} \cdot \sinh \left(\sqrt{\frac{S_w}{c}} \cdot \frac{L}{2} \right) \quad (2.2.5)$$

or using

$$c' = \frac{2c}{L} \quad S' = \frac{S}{c'} \quad \text{and} \quad S_w' = \frac{S_w \cdot L}{2c'}$$

to

$$\frac{p_2}{p_1} = \cosh \sqrt{S_w'} + \frac{S'}{\sqrt{S_w'}} \sinh \sqrt{S_w'} \quad (2.2.6)$$

Equ. (2.2, 4) is transformed to

$$\frac{p_2}{p_1} = 1 + \frac{S \cdot L}{2c} \quad (2.2.7)$$

or

$$\frac{p_2}{p_1} = 1 + S' \quad (2.2.8)$$

The pump giving the pumping speed S is actually a combination of a liquid nitrogen cooled titanium sublimation pump and a sputter ion pump, pumping through an orifice. As the pumping speed of the two pumps is very much larger than the

conductance of the orifice, the pumping speed S , seen by the rest of the vacuum system, is only determined by the conductance of the orifice which can be calculated. Actual values, using CO as gas and the LEP test chamber are

$$\begin{aligned} S &= 58 \text{ ls}^{-1} \\ c &= 147 \text{ ls}^{-1} \text{ m} \\ S' &= 1.38 \end{aligned}$$

The conductance c was determined using equ. (2.2.7) and injecting CO at the upstream end. Before this measurement the system had been up to air, pumped down and baked at 150°C , so that the wall pumping speed was zero. After glow discharge, the CO injection was repeated, and the ratio p_2/p_1 changed by more than a factor of 10. The wall pumping speed was now determined by solving equ. (2.2.5) graphically or numerically. During the CO exposure the ratio p_2/p_1 moved gradually to the value before glow discharge. The wall pumping speed dropped thus to zero. Figure 9 shows values of the wall pumping speed as a function of the CO dose as calculated by integrating the average of the pressures p_2 and p_1 over time. This is, of course, not quite correct because the wall saturates at the upstream end first but it nevertheless gives an idea of its capacity.

2.3 Desorption yield

In order to determine the efficiency of the discharge cleaning process, electron induced desorption yields were measured. The measurements were performed using a mobile device which emits electrons from a filament at an energy of $\sim 250 \text{ eV}$ and a current of $\sim 100 \mu\text{A}$. The whole device, including rechargeable batteries and the necessary electronics was enclosed in a vacuum tight stainless steel envelope (Fig. 10). In order to measure desorption yields on different positions along the test chamber, the device could be moved from outside with magnets. The quantities of different gases desorbed were measured using the method of ref. 11). This method employs a Bayard-Alpert gauge and a residual gas analyzer both calibrated for every single gas investigated and measures the partial pressure increases just upstream of a known pumping speed. The same pumping system as described in section 2.2 was used.

Effects of argon and helium glow discharges, bakeouts and venting were investigated in various combinations. The discharge parameters for helium and argon were chosen from the results of section 2.1 and are marked as a cross in figures 6 and 8 respectively.

The electron induced desorption yields observed for different desorbed gases and different treatments are displayed in table 1. Actually, the figures represent the yields observed in the centre section of the test chamber. Towards the ends, special end effects, discussed later on, seem to disturb the results. It should be noted that the LEP test chamber was the same which was used for experiments on the distribution of the discharge. It was, therefore, before the beginning of the events summarized in table 1, subjected to extensive glow discharge treatments. Prior to installation, the chamber was only subjected to a vapour degreasing treatment. No attempt was made to correct the desorption yields observed for the effects of wall pumping.

The main features observed are a fairly efficient reduction of the desorption yields for CO and CO₂ by the argon as well as the helium discharge. The yield for CH₄ levels off around $2 \cdot 10^{-4}$ molecules per electron and the yield for H₂ around $2 \cdot 10^{-2}$ and $3 \cdot 10^{-3}$ mol/e⁻ for argon and helium discharge respectively. There is also a remarkably high desorption of the discharge gas used. Venting of the system to air resets the yields to values comparable to the ones observed before discharge with the exception of the discharge gas itself which stays at or slightly below its level of desorption yields before venting. Figures 11 and 12 summarize the reduction of different desorption yields as a function of discharge time for argon and helium discharge respectively. The curves are composed of results from different treatments with venting of the system to air in between. Two sorts of effects, resulting in a position dependence of desorption yields were observed. The yield for helium was strongly increased towards the upstream end after a discharge with simultaneous or subsequent bakeout at 140°C nominally. (Fig. 13). After a cold helium glow discharge the yield for helium is higher than the highest points in Figure 13 throughout the length of the chamber. The yield of CO and CO₂ has been increased by bakeout after a glow discharge specially at the downstream end (fig. 15).

3. Discussion

3.1 Properties of the glow discharge

The results from section 2.1 show that it is, by suitable choice of the discharge current and the gas pressure, possible to make a glow discharge spread out all over a 7 m long chamber using the linear pump structure as anode. This requires, depending on the discharge gas used, minimum currents between 0.7 and 1.4 A, i.e. 100 to 200 mA. The fact that the discharge has to penetrate through narrow slits into the main channel poses no particular problem. It might,

however, explain the fairly high pressure at which optimum conditions have been found. It is tempting to attribute the better behaviour of the discharge in the LEP test chamber as compared to the PETRA one to the bigger width of the slots between main channel and pump channel (9 mm versus 5 mm). Under suitable conditions the discharge extends also beyond the linear ion pumps used as anode. This opens a possibility to bridge chamber connections and, very likely, even the 4 m long quadrupole chambers¹⁾ without special anodes installed in the vacuum chamber. In the LEP machine a vacuum chamber will be ~12 m long, which means that a single anode has to serve 12 to 14 m (12 m regular chamber + $\frac{1}{2}$ quadrupole chamber) of discharge. There is some evidence that the upper current limit at which arcing sets in does not depend on the size of the chamber¹²⁾. If then the lower current limit at which the whole chamber is covered with discharge is proportional to the size of the chamber, the region of suitable conditions (see Section 2.1) in Figures 6 to 8 becomes considerably smaller. Nevertheless, at least for helium and neon a sufficiently large region of suitable discharge conditions should be available. The destruction of the surface by arcs can be avoided by using half-wave rectified current¹²⁾.

3.2 Electron induced desorption yield

Table 2 shows a comparison of some of the present data with results obtained by other authors. The data are, as the large differences between different authors suggest, not strictly comparable. Except for the different electron energies and alloys used, there are very different cleaning methods used prior to installation of the sample in the vacuum system. They range from degreasing in solvent vapour in the present work via degreasing combined with detergent cleaning^{2,6,7,8,13)} to chemical attack^{3,6)}.

There are also considerable differences in the experimental set-up. The set-ups range from systems with small samples inside a test chamber^{2,7,8,13)} via a large tube like sample in a chamber⁶⁾ to set-ups which use the surface of a vacuum chamber as sample^{3,17)} like the system used to perform the present work. It is, of course, hard to tell which difference in values of desorption coefficients observed should be attributed to which difference in experimental arrangements. The most marked difference between present results and other authors' results is the high desorption yield of Ar after an Ar discharge. This might be due to the large dose of Ar-ions, impinging on the chamber wall during all the experiments described in section 2.1 or due to deposition of sputter material on adsorbed Ar layers, the deposition of sputter material on the sample being a particular effect of closed geometry. The existence of a cumulative effect seems to be, at least in the case of He, very unlikely as the He desorption

for Ar and He are really produced by covering adsorbed layers with sputter material, then these yields should depend on temperature and pressure during discharge. For the pressure effect, a comparison with results from ref. (3) obtained with a 100 times lower Ar pressure seem to be consistent with a proportionality between pressure and Ar desorption yield. The results in Table 1 show that higher temperature reduces the Ar or helium desorption yield. The desorption yields for hydrogen and methane stay even after many glow discharge treatments, two to four orders of magnitude higher than similar values quoted in Ref. 3, whereas they compare quite well with Edward's results⁶⁾. The present results for CO and CO₂ after glow discharge are compatible with other authors' results in the sense that they are very low. An effect which might upset the results for CO and CO₂ after glow discharge is the strong wall pumping of these gases⁶⁾. Fig. 16 gives the observed yield as compared to the real yield for CO for different wall pumping speeds and different positions along the chamber as calculated by the solution of equ. (2.3.1) with adequate border conditions. It is evident that this effect could give rise to corrections of several orders of magnitude. On the other hand, high wall pumping speeds are helpful in reducing the radiation induced pressure rise. One might therefore argue that even in the case where the real yields are higher than the results quoted, the results in Table 1 represent the real situation.

The desorption yields for H₂ and CH₄ have been found to be within the limits of error independent of position along the test chamber. Dependence on position has been observed for Ar, He, CO and CO₂. Yields for CO and CO₂ are higher at the downstream end of the test chamber (Fig. 15). This might be due to recontamination starting from the not glow discharge cleaned stainless steel part of the apparatus or due to an effect of wall pumping as described above (Fig. 16).

After a glow discharge performed at bakeout temperature or a glow discharge with subsequent bakeout, the desorption yield for He or to a lesser extent for Ar is higher on the upstream end of the test chamber (Fig. 13). This is most probably an effect of varying bakeout temperature along the test chamber. Fig. 14 shows the He desorption yields after He glow discharge and subsequent bakeout as a function of the temperature of the corresponding point of the test chamber during bakeout.

In an earlier paper⁹⁾ an effect, which, due to interaction between cleaning, recontamination and gas flow, gives a fairly sharp transition between the clean and contaminated portion of the test chamber, has been predicted. This

transition would move slowly in the direction of the gas flow. In the present experiment, no such effect was found. This most likely means that the gas molecules originally adsorbed on the internal surface of the test chamber are not moved out by the gas flow but are buried in sputtered material or ionized and injected into the wall. This implies that in contrast to assumptions based on theoretical considerations⁹⁾, the velocity of the gas flow cannot influence the cleaning efficiency dramatically.

3.3 Beam gas bremsstrahlung lifetime

Table 3 shows estimates of the initial beam lifetime by residual gas interactions in LEP. The calculations are based on the formulae from ref. 10). The beam energy has been set to 50 GeV, and the maximum energy loss in a collision, which does not cause an electron to be lost, to 1% of the total energy. Changing these parameters throughout the range suitable for LEP does not change the results by more than 30% towards longer or 5% towards shorter lifetime. The interactions taken into account are Bremsstrahlung on nuclei and electrons, elastic scattering giving negligible contributions. The theoretical lifetime with 1.10^{-9} torr of any one of the following gases as the only residual gas is :

H ₂	535 hours
He	413 hours
CH ₄	66 hours
CO	34 hours
Ar	14 hours
CO ₂	21 hours

To calculate the beam induced pressure rises in Table 3, 10 mA total beam current have been assumed producing 1 mA of photoelectrons per metre of vacuum system. This photoelectron yield is lower than earlier estimates¹⁴⁾ but preliminary results from an experiment using synchrotron light¹⁵⁾ suggest that this is a more realistic assumption. The pumping speeds quoted for the ion pumps correspond to the LEP proposal¹⁾ at 50 GeV. The pumping speeds for the pumping system using Non Evaporable Getters¹⁶⁾ and auxiliary ion pumps are assumptions based on present discussions. The large pumping speeds for H₂, CO and CO₂ are produced by the getter, the small pumping speed for CH₄, He and Ar by the auxiliary ion pumps (thought to be arranged like the holding pumps of ref. 1).

The results show several interesting features. First, argon desorption constitutes a major limitation in the case of an argon glow discharged system. If, however, helium is used to perform the glow discharge, the limitation by helium desorption is much less severe. In the case of a system pumped by NEG (Non Evaporable Getter) pumps, CH_4 is always an important problem. After the glow discharge treatment, desorption of CO and CO_2 is no longer a problem. Even if the beam induced pressure rise for CO and CO_2 after glow discharge would be 10 times higher than quoted in Table 3, the influence on the total lifetime would still not be catastrophic. It would, nevertheless, be an interesting experiment to measure wall pumping speed and desorption yield in one single experiment. A more important question to investigate would be the reason for the fairly high desorption yield of H_2 and CH_4 . A possible explanation might be the fact that the chamber was only degreased with an organic solvent and not detergent cleaned or rinsed prior to installation. Another question to be answered is the behaviour of a virgin chamber with respect to its desorption yields. Further points to be investigated are the behaviour of discharge cleaned surfaces under irradiation, the minimum necessary flow and cleanliness of the discharge gas and the practical implementation of a glow discharge cleaning method in a very large machine.

In particular, with respect to the use of pumps which do not pump rare gases, the use of active gases for the glow discharge should be considered. In fact, for discharge cleaning plasma machines, hydrogen is the usual choice⁵⁾. Hydrogen or nitrogen might be considered in the present case.

4. Conclusion

It has been demonstrated that, by using a suitable glow discharge cleaning method, the electron induced desorption yield inside the LEP vacuum chambers can be significantly reduced. Thus an initial beam lifetime of several hours could be obtained requiring a modest pumping speed. The discharge should, however, be performed using helium instead of argon as helium, due to its low atomic number, has a by far lesser influence on the beam lifetime. For a vacuum system pumped by getters the gain in initial lifetime, achieved by glow discharge treatment, is less important due to the high pumping speed. Furthermore, it could quickly be offset by progressing beam cleaning in a system without glow discharge treatment.

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Table I'

Treatment	Desorption yield					
	H ₂	He	CH ₄	CO	Ar	CO ₂
glow discharge (many treatments) up to air	0.18	-	0.013	0.018	3 10 ⁻³	0.02
20 h bakeout	0.15		0.015	0.03	1.5 10 ⁻³	0.015
6 h Ar glow discharge 0.5 torr, 2 A	0.015		1.5 10 ⁻⁴	8 10 ⁻⁵	1.5 10 ⁻²	6 10 ⁻⁶
up to air	0.15		0.02	0.05	1 10 ⁻²	0.05
16 h bakeout 3 h Ar glow discharge 20 h bakeout	0.09		1.8 10 ⁻³	3 10 ⁻³	7 10 ⁻⁴	3 10 ⁻⁴
3 h Ar glow discharge 140°C, only test chamber heated	0.015		1.5 10 ⁻⁴	2.5 10 ⁻⁵	1.5 10 ⁻³	5 10 ⁻⁶
36 h bakeout at 140°C of test chamber only	0.03		6 10 ⁻⁴	7 10 ⁻⁵	3 10 ⁻⁴	5 10 ⁻⁶
up to air 20 h bakeout	0.08	<10 ⁻⁶	5 10 ⁻³	0.015	4 10 ⁻⁴	4 10 ⁻³
3 h He glow discharge 5 A 1.5 torr	2 10 ⁻³	0.03	1 10 ⁻⁴	2 10 ⁻⁵	5 10 ⁻⁴	5 10 ⁻⁶
20 h bakeout 140°C test chamber only	0.015	2 10 ⁻⁴	6 10 ⁻⁴	2 10 ⁻⁴	8 10 ⁻⁵	2 10 ⁻⁵
up to air, 20 h bakeout, 3 h He glow discharge, 5 A 2 torr 140°C, 4 h bakeout	7 10 ⁻³	1.5 10 ⁻⁴	3 10 ⁻⁴	2 10 ⁻⁴	2 10 ⁻⁵	7 10 ⁻⁵
2 h up to air 20 h bakeout	0.02	7 10 ⁻⁵	10 ⁻³	3 10 ⁻³	3 10 ⁻⁵	1 10 ⁻³
3 h He glow discharge 2 torr 5 A 140°C	3 10 ⁻³	1.5 10 ⁻³	2 10 ⁻⁴	1.5 10 ⁻⁵		<10 ⁻⁶
4 h bakeout 140°C only test chamber	3 10 ⁻³	3 10 ⁻⁴	2 10 ⁻⁴	1.5 10 ⁻⁵		5 10 ⁻⁶
18 h bakeout 140°C whole system baked	0.01	1.5 10 ⁻⁴	3 10 ⁻⁴	3 10 ⁻⁵		5 10 ⁻⁶

Table 2

treatment	e ⁻ energy	alloy	desorption yield					reference
			H ₂	CH ₄	CO	Ar	CO ₂	
cleaned, pumped	600	5086	5.5	0.55	1.8	-	2.2	7
	300	Extrudal	32.6	0.53	3.7		2.1	3
	300	Extrudal	0.3	0.03	0.09		0.07	8
	600	pure Al	0.9	0.25	1.5		3	13
	300	6061-T6	6.8 10 ⁻³	2.3 10 ⁻⁴	0.035		2.2 10 ⁻³	17
cleaned, pumped, baked 150°C	600	5086	2.5	0.07	0.5		0.5	7
	300	Extrudal	0.08	5 10 ⁻³	0.015		9 10 ⁻³	8
	500	6061	0.3	7 10 ⁻³	0.1		0.3	6 (200° bake)
	600	pure Al	0.13	7 10 ⁻³	4 10 ⁻²		3 10 ⁻²	13 (300° bake)
	300	6061-T6	2.6 10 ⁻⁵	8.1 10 ⁻⁵	1.5 10 ⁻³		2.4 10 ⁻⁶	17 (200° bake)
cleaned, Ar glow discharge, up to air, pumped	300	Extrudal	0.05	7 10 ⁻³	0.01		0.03	8
	250	Extrudal	0.18	0.013	0.018	3 10 ⁻³	0.02	present work
cleaned, Ar glow discharge, up to air, baked	300	Extrudal	0.03	1.2 10 ⁻³	3 10 ⁻³		1.5 10 ⁻³	8
	250	Extrudal	0.15	1.5 10 ⁻²	3 10 ⁻²	1.5 10 ⁻³	1.5 10 ⁻²	present work
	300	Extrudal	0.26	8.7 10 ⁻³	5.3 10 ⁻²		1.6 10 ⁻¹	3
cleaned, baked, Ar glow discharge	300	Extrudal	2.1 10 ⁻⁵	6.4 10 ⁻⁸	9.1 10 ⁻⁸	3.1 10 ⁻⁶	2.6 10 ⁻⁷	3
	2000	pure Al	<10 ⁻³	<10 ⁻³	<10 ⁻³		<10 ⁻³	13
	500	6061	10 ⁻²	<10 ⁻³	<10 ⁻²		<3 10 ⁻²	6 (200° bake)
	250	Extrudal	1.5 10 ⁻²	1.5 10 ⁻⁴	<8 10 ⁻⁵	1.5 10 ⁻³	<6 10 ⁻⁶	present work
	300	6061-T6	1.5 10 ⁻⁴	1.1 10 ⁻⁶	2.2 10 ⁻⁶	7.7 10 ⁻⁷	<10 ⁻⁸	17 (200° bake)

Table 3

Gas	Ion Pumps				Non evaporable getter pumps + auxiliary ion pumps		
	Pumping speeds (ls ⁻¹ m)						
H ₂	30				500.0		
He	10				2.5		
CH ₄	30				2.5		
CO	30				200.0		
Ar	10				2.5		
CO ₂	30				200.0		
	desorption yield	pressure rise (torr) (10 mA)	inverse lifetime h ⁻¹	per cent of total inverse lifetime	pressure rise (torr) (10 mA)	inverse lifetime h ⁻¹	per cent of total inverse lifetime
baked system (ref. 8)							
H ₂	8 10 ⁻²	1.04 10 ⁻⁶	1.94	14	6.24 10 ⁻⁸	0.12	1
CH ₄	5 10 ⁻²	6.5 10 ⁻⁸	0.98	7	7.8 10 ⁻⁷	11.8	87
CO	1.5 10 ⁻²	1.95 10 ⁻⁷	5.74	40	2.9 10 ⁻⁸	0.85	6
CO ₂	9 10 ⁻³	1.17 10 ⁻⁷	5.57	39	1.76 10 ⁻⁸	0.83	6
total	1.42 10 ⁻⁶ 14.23				8.9 10 ⁻⁷ 13.6		
Ar glow discharged system							
H ₂	3 10 ⁻²	3.9 10 ⁻⁷	0.72	42	2.3 10 ⁻⁸	0.04	1
CH ₄	6 10 ⁻⁴	7.8 10 ⁻⁹	0.12	7	9.4 10 ⁻⁸	1.42	29
CO	7 10 ⁻⁵	9.1 10 ⁻¹⁰	0.03	2	1.37 10 ⁻¹⁰	-	-
Ar	3 10 ⁻⁴	1.17 10 ⁻⁸	0.83	49	4.7 10 ⁻⁸	3.36	70
CO ₂	5 10 ⁻⁶	6.5 10 ⁻¹¹	-	-	9.8 10 ⁻¹²	-	-
total	4.1 10 ⁻⁷ 1.7				1.64 10 ⁻⁷ 4.82		
He glow discharged system							
H ₂	3 10 ⁻³	3.9 10 ⁻⁸	0.072	49	2.3 10 ⁻⁹	0.004	1
He	3 10 ⁻⁴	1.17 10 ⁻⁸	0.028	19	4.7 10 ⁻⁸	0.114	19
CH ₄	2 10 ⁻⁴	2.6 10 ⁻⁹	0.039	26	3.1 10 ⁻⁸	0.470	80
CO	1.5 10 ⁻⁵	1.95 10 ⁻¹⁰	0.006	4	2.9 10 ⁻¹¹	0.001	-
CO ₂	5 10 ⁻⁶	6.5 10 ⁻¹¹	0.003	2	9.8 10 ⁻¹²	-	-
total	5.36 10 ⁻⁸ 0.148				8 10 ⁻⁸ 0.589		
	Lifetimes for 10 mA total beam current (hours)						
	baked	Ar glow discharge			He glow discharge		
ion pumps	.07	.59			6.75		
NEG pumps	.07	.21			1.70		

Figure Captions

- Fig. 1 Schematics of the vacuum system and test chamber. Insert 1b shows the profile of the LEP test chamber.
- Fig. 2 Sample current density distribution for 0.5 torr 2 A argon discharge.
- Figs. 3-8 Regions of different discharge types (see Section 2.1).
- Fig. 9 Wall pumping speed after an argon glow discharge. The wall gets gradually saturated by application of CO.
- Fig. 10 Mobile desorption device. The filament emitting the electrons is on the lower left end.
- Fig. 11 Reduction of desorption yields during argon discharge. The curves are composed of several different experiments.
- Fig. 12 Reduction of desorption yields during helium discharge. The curves are composed of several different experiments.
- Fig. 13 Helium desorption yields after a helium discharge (3 hours, 5A, 140°C, 1.5 torr reduced pressure) with subsequent 140°C bakeout.
- Fig. 14 Helium desorption yields versus actual temperature during bakeout (same data as in Fig. 13).
- Fig. 15 Apparent CO₂ desorption yields after a helium discharge (3 hours, 5A, 140°C, 1.5 torr reduced pressure) with subsequent bakeout.
- Fig. 16 Ratio of real to apparent desorption yields for CO for different wall pumping speeds, obtained by the solution of Equ. 2.2.1.

Fig. 1a

Fig. 1b

FIG. 2

FIG. 3

PETRA CHAMBER
NEON DISCHARGE

FIG. 4

PETRA CHAMBER
ARGON DISCHARGE

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

Fig. 10

ELECTRON INDUCED DESORPTION COEFFICIENT
(MOLECULES / ELECTRON)

FIG. 11

ELECTRON INDUCED DESORPTION COEFFICIENT
(MOLECULES / ELECTRON)

FIG. 12

HELIUM DESORPTION COEFFICIENT
(ATOMS/ELECTRON)

FIG. 13

FIG. 14

CO₂ DESORPTION COEFFICIENT
(MOLECULES/ELECTRON)

FIG. 15

APPARENT DESORPTION COEFFICIENT
REAL DESORPTION COEFFICIENT

FIG. 16