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A NEW DEFLECTED BEAM GAUGE FOR PRESSURES BELOW 10^{-12} TORR

by

D. Blechschmidt

Abstract

Design and performance of a new hot filament ionization gauge, especially developed for total pressure measurements down to 10^{-14} torr, are described. The gauge features an electrostatically deflected ion beam which is directed at the funnel cathode of a small CEM (channel electron multiplier). The spurious signal due to electronic desorption of ions from the anode is extremely small, because these ions are typically of higher initial total energy than those from the residual gas, and may therefore be evicted from the high energy side of the ion beam that is energetically dispersed by the deflecting electric field. The x-ray background corresponds to a pressure in the 10^{-14} torr range, and since it can be measured just by inverting the deflector potential, it may easily be zeroed out electronically. Almost none of the secondary particles, released by x-rays or ions from the deflecting electrodes, is counted, because the CEM cathode is operated at high negative potential and because most positive secondary ions are collected at the negative deflecting electrode, due to their small kinetic energy. The gauge's sensitivity for nitrogen is about 10^{17} counts/s.torr.A, corresponding to 10^5 torr $^{-1}$ for a CEM gain of 10^7 . It is mounted on a 113.5 mm metal flange with ceramic feedthroughs and may be baked up to about 300°C.

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1. INTRODUCTION

Total pressure measurements below 10^{-12} torr have been so far of academic interest mainly, since vacua of this order of magnitude are not only difficult to achieve but also hardly ever necessary. The Intersecting Storage Rings at CERN, however, are operated at pressures that are typically less than 5×10^{-12} torr in the crossing regions of the proton beams, in order to decrease the number of spurious events that arise from protons interacting with residual gas molecules ¹⁾. An even better vacuum might become desirable in particular intersections for this same reason, it will be provided by special cryopumps, designed to achieve ultimate pressures of less than 10^{-13} torr ²⁾. Hence, a total pressure gauge for this vacuum range must have an extremely low pressure limitation together with a high sensitivity.

The two major processes limiting a total pressure gauge in the low pressure range are the well known x-ray effect and electron impact desorption of ions from the anode. The x-ray limit may be reduced using special geometries providing a smaller solid angle subtended by the ion collector at the anode, whilst the ion collection efficiency is almost kept constant. Desorbed ions are typically of higher kinetic initial energy, than ions that are created from residual gas molecules, and may therefore be suppressed using ion optics to reduce the gauge's low pressure limit.

It seems, however, impossible to extend the working range of any gauge to below 5×10^{-13} torr by these means only, i.e. without increasing the sensitivity by using a multiplier as the ion detector. Even the modulation technique ³⁾, which allows to extend a gauge's working range to below its normal low pressure limitation, fails, if the actual pressure is about one order of magnitude less than the limitation. This is because the difference between the modulated and unmodulated collector current becomes too small as to be measured accurately below 10^{-12} torr. The only hot filament ionization gauge of extremely high sensitivity but operating without a multiplier, the orbitron ⁴⁾, is limited in the low 10^{-11} torr range due to space charge effects ⁵⁾. The gauge sensitivity problem must therefore be solved using a multiplier as an ion detector in a total pressure gauge for $p < 10^{-12}$ torr ^{6,7)} in analogy to mass spectrometers. Channeltron

electron multipliers ⁸⁾, hereafter CEM, are particularly well suited for this purpose, since they are light weight, small and inexpensive.

Recently, a gauge model equipped with a CEM and developed for the pressure range below 10^{-12} torr, operating at about 1 μ A emission only, has been presented ⁷⁾. However its operation range was in fact found to be limited at about 10^{-12} torr due to recontamination of the anode grid by molecules diffusing from the grid's bulk to the surface and also due to x-rays, still causing a spurious signal. The latter effect had been neglected in the evaluation of the gauge's low pressure limit, since it was assumed that x-rays, due to their negligible momentum (compared with the ions) yield only secondary electrons that are low energetic and of diffuse directional distribution and therefore unable to travel from the semiconducting cathode through the throat of the CEM spiral, to which the negative cathode potential is in fact applied. Unfortunately, both effects, recontamination and x-rays, were just masked by the low pressure limitation of the reference gauge that was used for the low pressure measurements ⁹⁾. This limitation was recently found to be at about 2×10^{-12} torr due to the evaporation of tungsten from the hot filament ¹⁰⁾.

Fig. 1 is a photograph of the new model as presented in this paper, a schematical cutaway drawing is shown in Fig. 2. Residual gas molecules are ionized in the volume enclosed by two concentric grid cylinders by electrons emitted from the hot filament that is stretched out along the gauge's symmetry axis. The ionization volume is closed at the top and the ions produced therein are extracted through a pair of collimating circular slots in two parallel, and grounded electrodes, one of which closes the grids base and the other is mounted further below. The ion beam leaving this collimator is then deflected towards the gauge's symmetry axis in the electric field between two concentric semispherical electrodes, the outer one of which is grounded and the inner one biased negatively and therefore referred to as the deflector. With the correctly chosen deflector potential, only ions of low kinetic energy are extracted through a small aperture at the base of the outer sphere, whereas ions of high kinetic energy impinge at this electrode and are neutralized. The funnel of a

small CEM that is mounted beneath and operated at high negative potential, collects extracted ions and gives rise to a negative output pulse for almost every single ion, which may then be counted electronically. Of course, the beam is dispersed only with respect to ion energy but regardless of the ion's charge to mass ratio.

The new design features the following characteristics that qualify the gauge for total pressure measurements below 10^{-12} torr:

(a) x-rays, emitted from the anode have to be reflected at least twice (assuming specular reflection), before they hit the CEM cathode;

(b) the residual x-ray flux to the CEM cathode may be measured at positive deflector potential, where the total ion beam is neutralized at the outer sphere, whereas the x-ray flux remains unaffected. The x-ray induced spurious signal may hence be evicted electronically;

(c) desorbed ions from the anode have a higher initial total energy than residual gas ions from within the ionization volume. The extraction of only the low energy tail of the ion beam provides an optimal suppression of a spurious signal due to electronic ion desorption from the grid;

(d) the high negative potential of the CEM funnel prevents secondary electrons and photoelectrons, released from the deflecting electrodes by ions or x-rays, to cause a pressure independent background signal, quite unlike the situation of the Helmer gauge ⁹⁾. Almost all positive secondary ions are neutralized at the deflector due to their small initial kinetic energy;

(e) the axial position of the filament that is almost completely enclosed by the circular anode grid structure prevents the accumulation of space charge in case of an incorrectly biased cathode and makes the sensitivity independent of the gauge's position with respect to the walls of the vacuum system;

(f) the CEM provides a sensitivity of many orders of magnitude higher than that of a normal Bayard-Alpert gauge, therefore the emission current may be reduced accordingly. Since the cathode is thorium coated,

the filament power dissipation is very small and therewith the thermal outgassing of irradiated surfaces; furthermore, the evaporation rate of tungsten from the cathode becomes negligible.

2. CONSTRUCTION

The deflected beam gauge is shown in Fig. 1. The cathode is a 30 mm long, thoria coated tungsten filament of 0.2 mm diam of helicoidal shape, supported by 1.5 mm diam tungsten rods. The anode grid, made from 0.15 mm Pt90Ir wire is 30 mm high; the inner and the outer grid cylinder walls have a radius of 10 and 20 mm, respectively. Grid and filament are mounted at a removeable support ring that is fixed to a cylindrical screen protecting the deflector electrodes and the CEM from stray electric fields and x-rays.

In order to shield the ion paths electrically from the filament supports and deflector connection rods, a sector of 30° is removed from the grid cylinders. The filament support bars are fed through this sector above the upper collimator plate and the deflector connector below it. The two collimator apertures, of which the inner and outer edges have a radius of 12 and 15 mm, are cut into the top face of the cylindrical screen body (lower plate) and into a disk mounted parallelly 7.5 mm above (upper plate). The collimator stops ions which paths are inclined by more than 17° against the gauge's symmetry axis. The collimator apertures are symmetric with respect to the grid's open base, their sector angle is 270° .

The semispherical deflecting electrodes are made from 0.15 mm stainless steel and aligned with great care as to provide the required energy resolution; their radii are 10 and 17 mm, respectively. The small circular extraction aperture at the base of the outer sphere is 3 mm in diam. Therefore, only ions which paths are inclined by less than 5° with respect to a meridian through the center of this aperture, are extracted. These dimensions proved to be a good compromise between ion energy resolution and extraction efficiency: although only one percent of the ions leaving the collimator are extracted to the CEM.

The CEM funnel cathode is mounted about 3 mm below the extraction aperture. Its open anode is grounded and a small stainless steel plate collects the electrons leaving it.

The gauge head is mounted on a standard 113.5 metal flange with ceramic feedthroughs; the gauge's total height is about 100 mm. All components, made from stainless steel and all alumina insulators, (i.e. except from the CEM, the grid, the filament and the flange) were pretreated at about 1000°C in a vacuum furnace and at a pressure of less than 10^{-4} torr in order to reduce the intrinsic outgassing rate. The flange together with the feedthroughs was baked at 450°C for several hours.

3. ION TRAJECTORIES

The working principle of the deflected beam gauge is new, therefore its optimal geometric and electronic parameters had to be found. Many different designs were investigated using a ion tracing computer programme, before a prototype was built and tested experimentally. The design parameters as given in this paper, are concerned with the final result, which were the best with respect to ion transmission (i.e. sensitivity), to energy resolution (i.e. low electron induced ion desorption background), and to shielding the CEM funnel from x-rays, that emanate from the grid.

In order to determine a ion's path in the electric field between the deflecting electrodes, the Lagrange equations have to be solved for the potential

$$\phi(\underline{r}) = a(1/r - 1/r_2) \quad \text{with} \quad a = U_d r_1 r_2 / (r_2 - r_1) ; \quad (1)$$

where U_d denotes the deflector potential (applied to the inner-sphere); the parameters r_1 and r_2 are the radii of the inner and outer sphere, respectively, and $r = |\underline{r}|$. Hence, with spherical coordinates

$$\underline{r} = (r \sin \theta \cos \phi; r \sin \theta \sin \phi; r \cos \theta) \quad (2)$$

and setting the ion's charge-to-mass ratio arbitrarily to unity, since there is no momentum resolution in an electric field, the equations of motion become:

$$\begin{aligned} \ddot{r} &= a/r^2 + r(\dot{\theta}^2 + \dot{\phi}^2 \sin^2 \theta) \\ \ddot{\theta} &= \frac{1}{2} \dot{\phi}^2 \sin 2\theta - 2r\dot{\theta}/r \\ \ddot{\phi} &= -2\dot{\phi}(r/r + \dot{\theta}/\tan \theta) ; \end{aligned} \quad (3)$$

the dots denote differentiation with respect to time.

Using Eqs. (3), the ions may be traced by the computer until they "impinge" at either one of the semi-spheres, or collimator plates, "return" to the ionization volume, or "pass" through the extraction aperture whereupon they are collected at the CEM funnel. The initial conditions are given by

$$\underline{r}(t=0) = (r_0; 0; 0) \quad \text{and} \quad |\dot{\underline{r}}(t=0)| = v_0 = \left(2(U_g - \Phi(\underline{r}_0)) \right)^{\frac{1}{2}}, \quad (4)$$

i.e. it has been assumed that an ion enters the collimator with the energy that is equivalent to that of an ion starting from a point at grid potential U_g , with zero kinetic initial energy. Finally, the initial velocity of the ion is obtained from the equations

$$\begin{aligned} \dot{r}_0 &= v_0 \sin \alpha \cos \beta; & \dot{\theta}_0 &= -v_0 \cos \alpha / r_0; \\ \text{and } \dot{\phi}_0 &= v_0 \sin \alpha \sin \beta / r_0, \end{aligned} \quad (5)$$

where α and β are its azimuthal and horizontal angle of initial direction, respectively.

Ion trajectories for significant initial conditions as drawn in Fig. 3, have been computed in order to obtain information about the gauge's performance. The influence of the electric field inhomogeneity between the collimator and the spheres has been neglected in a first approximation, since the slit apertures are smaller than the distance between the semi-spheres. The results are given in Table I as the ratio $-U_d/U_g$ for which an ion is either extracted to the CEM, or neutralized at the outer or inner collimator edges. Keeping in mind, that for decreasing deflector potential U_d , the ion impinges first at the outer sphere, is then extracted, hits the outer sphere again and so on until finally it is neutralized at the inner sphere at the most negative U_d voltage, $-U_d/U_g$ values for any intermediate case are obtained accordingly.

Due to geometrical reasons, as already mentioned in the proceeding chapter, ions with initial directions given by $\alpha > 5^\circ$, $\beta \approx \pm 90^\circ$ (see

Equ. (5)), cannot be extracted. On the other hand, results from ion tracing with $\alpha \leq 5^\circ$ and $\beta = \pm 90^\circ$ do not differ essentially from those with $\alpha = 0^\circ$. Therefore, only cases with $\beta = 0^\circ$ or 180° were studied, i.e. which ions are extracted at different deflector potentials. Table I shows, that ions get to the CEM only for $-U_d/U_g$ in the range from 0.39 to 1.41, depending on their initial direction. Furthermore, it can be seen that the energy resolution is better for ions created near the inner grid cylinder than for those originating near the outer one.

4. MEASUREMENT OF PERFORMANCE

The gauge's performance was tested mainly in all metal UHV system with an ultimate pressure of some 10^{-12} torr, achieved by a sputter-ion pump and two liquid nitrogen cooled titanium sublimation pumps. A Helmer gauge (Varian Ass., Palo Alto, USA) was used as the reference. Since, however, the basic pressure in this system was not low enough as to test the gauge's low pressure behaviour and also because accurate pressure measurements with the Helmer gauge were not possible below 2×10^{-12} torr due to its limitation, the deflected beam gauge was mounted at another system with a basic pressure of only 4×10^{-13} torr. The pressure in this system was measured with a quadrupole mass spectrometer equipped with a secondary electron multiplier and calibrated below 10^{-10} torr by a modulated Bayard-Alpert gauge of extremely low pressure limitation (both from Balzers A.G., Liechtenstein). Since the residual pressure in this vacuum range in a metal system is mainly due to hydrogen, the calibration, as well as the measurements of sensitivity and linearity of the deflected beam gauge, were carried out with injected hydrogen, using the height of the H_2^+ peak in the mass spectrum as the pressure indication. The main disadvantage of the second system was the high bakeout temperature (about 350°C), that was required to achieve the ultimate pressure. Since this caused the CEM gain to impair drastically¹¹⁾, most measurements have been carried out in the system of "high" ultimate pressure of some 10^{-12} torr.

The grid of the deflected beam gauge was degassed at $p < 10^{-8}$ torr for 20 min by electron bombardment at an emission current of 100 mA

and with the grid at +700 V, after the system had cooled down to 150°C following a 24 h bakeout at 300°C. Then the gauge was operated at 10 mA continuously in order to prevent readsorption of residual gas at the anode. During all tests, the cathode-to-grid potential was 120 V; all variations of the grid potential U_g were done via the filament bias.

It was found that U_f had only a small influence on the performance, therefore it was usually set to +10 V (i.e. $U_g = 130$ V) in order to yield the smallest possible kinetic ion energy but also high enough to prevent electrons from the filament to bombard the collimator disk or the walls of the vacuum system. All measurements hereafter are concerned with the parameters given in Table II, unless otherwise mentioned.

A) Deflector potential

Fig. 4 is a plot of the deflected beam gauge's counting rate measured as a function of $-U_d/U_g$. Curves obtained for different U_g values are essentially congruent, only the peak height ratio becomes slightly changed in favour of the maximum at $-U_d/U_g \approx 2.2$ with increasing grid potential; the ratio is, however, constant with respect to pressure.

Results from computer ion tracing (see Table I) are inserted in Fig. 4 as bars, the horizontal position of which indicates the range of $-U_d/U_g$ where ions are either extracted (left bar), collide with one of the collimator plates or are retransmitted to the ionizing volume, (right bar). The different initial ion paths, as denoted by A through F are explained in Fig. 3. It is obvious from this figure that the left maximum is due to extracted ions, whereas the right one is caused by scattered primary ions or by secondary positive ions from the collimator edges.

The left maximum mainly seems to arise from ions with initial paths denoted by D and E, whereas it should have a position given by the bar for case C, describing a normal incident ion beam, centered with respect to the collimator apertures and created at potential U_g . However, the penetration of the deflection potential into the collimator tends to bend ion paths towards the deflector, i.e. paths like C at the collimator entrance become similar to D or even E at the exit. Furthermore, since ions from residual gas molecules are created at potentials less than U_g , they need

also a less negative deflector potential for extraction. Desorbed ions, however, starting with a few eV kinetic energy from the anode, have total initial energies exceeding eU_g and are therefore mainly found at the right side of the left maximum. Hence, very little desorbed ions are therefore extracted to the CEM for $U_d \geq 0.8 U_g$.

If the gauge's working point is at the left slope of the left maximum, the background of secondary or scattered positive ions is negligible since the maxima do not overlap; the level between them (at about $-U_d/U_g \approx 1.5$) is equal to the constant background that is persistent even at positive deflector potential. The fact, that the second maximum decreases with the gauge's time of operation and reappears after exposure to atmospheric pressure, supports the interpretation that it is only due to secondary positive ions from the collimator plates. Neither positive ions scattered at the deflecting electrodes nor secondary ions produced thereupon can be collected by the CEM for energetical reasons, since they will most likely be neutralized at the deflector.

The curve in Fig. 4 has a background of about 18 counts/s that is constant with respect to deflector potential and pressure. It is not due the CEM dark noise of about 0.5 counts/s which is almost completely suppressed by a pulse height discriminator. Because this background appears even at positive potential, where none of the ions produced in the ionizing volume can get to the CEM, and since it is proportional to the emission current, it must be due to x-rays.

B) Electronic Ion Desorption

The results from ion path computations have suggested that the gauge has to be operated with $U_d \geq -0.8 U_g$, in order to suppress the major part of desorbed ions. To check this suggestion experimentally, the gauge's output signal was measured as a function of the emission current at 2×10^{-12} torr for different parameters $-U_d/U_g$. The result is plotted in Fig. 5. The counting time was chosen to provide a statistical error of less than 10 percent. The x-ray background was not subtracted, because it was too small.

The counting rate is not proportional to the emission current (corresponding to a straight line of slope one in this plot) for parameters $-U_d/U_g \geq 1$ and $I_e \geq 0.3$ mA. For $-U_d/U_g \leq 0.6$, however, it rises linearly with I_e up to some 6 mA and deviates slightly for $-U_d/U_g = 0.8$ if $I_e > 1$ mA.

It is obvious from this result that electronic ion desorption from the grid is considerably reduced (even at high desorption rates for $I_e > 1$ mA) by operating the gauge at $U_d \geq -0.8U_g$, as already expected from the results shown in Fig. 4. At $-U_d/U_g = 0.7$ not only the signal to x-ray background is still very good, but also ion desorption may be neglected for $I_e < 5$ mA. Therefore, $U_d = -90$ V was chosen as the best operation parameter, see Table II.

C) Sensitivity

In order to obtain the gauge sensitivity but also to check whether it is constant at different pressures, the system was pumped to its basic pressure, and the gauge's counting rate measured as a function of the pressure of injected H_2 and N_2 , with an emission current of 10 μ A. The result is plotted in Fig. 6. From the slope of the two curves, sensitivities of 1.5×10^{17} counts/s.A.torr and 8×10^{16} counts/s.A.torr for nitrogen and hydrogen were found. The non-linearity at the curve's low pressure end is due to the limitation of the Helmer gauge, which was used as the reference in these measurements. The limitation obtained from this figure is 1.8×10^{-12} torr, being in close agreement with the result published by Angerth and Hulek¹⁰⁾.

D) X-ray limit

The output signal for any positive deflector potential is equal to the background at negative deflector voltage; since it is also constant with respect to time and pressure and since it rises linearly with the emission current at a rate of 6×10^3 counts/s.A and with a power of about 1.5 with the filament-to-grid potential, it must be due to x-rays. This signal corresponds to a spurious pressure indication of 4×10^{-14} torr. Although it is very small, it may easily be measured by inversion of the deflector potential and subtracted electronically.

E) Measurement of the total low pressure limit

In order to investigate, whether a total low pressure limitation can experimentally be obtained, the gauge was mounted at the second system of some 4×10^{-13} torr basic pressure. Unfortunately this system had to be baked at about 350°C , causing a considerable loss of the CEM gain. The gauge was therefore operated in the electrometer mode, which is described below.

The result for a hydrogen injection is plotted in Fig. 7: the collector current I_c is proportional to the H_2^+ peak height in the spectrum obtained with the quadrupole mass spectrometer down to $p = 6 \times 10^{-13}$ torr. Since the accuracy of current measurements in this range is still better than 10 per cent, the total pressure limitation must be less than 6×10^{-14} torr, and after subtraction of the x-ray background it is even better than 2×10^{-14} torr.

F) Measurement modes and gain

Pressure measurements may be performed either in the pulse counting mode, but also by measurement of the total electron current that leaves the CEM's open anode with an electrometer. The first method has the advantage that it may still be used at very low ion currents and that the true value of the CEM gain must not be known, provided it has a certain minimum value. Electrometer measurements are on the other hand easier to perform and may be carried out even at a CEM gain which is too low for the counting mode; their disadvantage is that the gain has to be known. Since, however, the gain decreases rapidly during bake-out¹¹⁾, or when the CEM is operated at high output currents of more than about 10^{-8} amps, it has to be determined from time to time.

The gain G can be obtained by measuring the x-ray induced collector current I_x (obtained for positive deflector potential) at emission I_e . It is

$$G = I_x / I_e, \quad (6)$$

where C is a constant, that may be found from the counting mode :

$$C = 1/en_x, \quad (7)$$

e denotes the elementary charge and n_x is the count rate per one amp emission current for positive deflector bias. Obviously, n_x only depends on the gauge geometry and the filament-to-grid potential which, however, are fixed parameters. For the gauge presented in this paper $n_x = 6000$ counts/s.A (see Table II) which yields $C = 10^{15}$.

In Fig. 8 the x-ray current and the current due to residual gas ions is drawn as a function of the CEM cathode potential U_k together with the ratio of the two curves. Using Equ. (6), a gain of 2×10^7 for example is obtained at $U_k = -3.5$ kV from this figure. Furthermore, one can see, that the x-ray induced low pressure limit decreases with rising cathode potential, due to a higher collection efficiency for ions together with a reduced probability for secondary electrons, produced at the CEM funnel by x-rays, to get into the throat of the CEM to which the negative high voltage is applied. Furthermore, it is evident from this figure, that the operation of the CEM for $U_k > -2.0$ kV, approximately its starting voltage, is unfavourable.

5. SUMMARY

A new hot filament ionization gauge of the deflected beam type has been presented. It is characterized by the following features:

- a) the x-ray induced low pressure limit is about 4×10^{-14} torr, which can easily be determined by inversion of the deflector potential and be subtracted electronically;
- b) the limitation due to electron impact ion desorption from the anode is negligible compared with the x-ray limit, provided the emission current is less than 5 mA. This is because desorbed ions are typically of higher initial energy than ions created from residual gas molecules, they may therefore be separated using the ion beam energy dispersion in the deflecting electric field;

- c) the filament heating power is very small, because the required emission current is low. Measurements at 10^{-12} torr for example can be carried out without difficulty at 10 μ A emission. Furthermore, the use of a thoria coated filament reduces the cathode temperature to below 1300 K, the tungsten evaporation from the cathode is therefore without influence on the gauge's low pressure limits.
- d) the filament is almost completely enclosed by the anode. Consequently, the cathode bias or the gauge's position with respect to the walls of the vacuum system has practically no influence on sensitivity or performance. Overheating of the filament due to an incorrect bias is also eluded.
- e) the use of a small multiplier provides an extremely high sensitivity (about 10^5 torr $^{-1}$ for a CEM gain of 10^7). Pressure measurements in the range far below 10^{-12} torr are thus without difficulties;
- f) the new gauge is relatively easy to operate, light weight and not very expensive. It is mounted at a 113.5 mm metal flange and may be baked to 300°C.

The deflected beam gauge will be miniaturized to the same size as of a special extractor gauge (mounted at a metal flange, fitting in an aperture of less than 15.7 mm diam. and with a limitation of 5×10^{-12} torr) especially developed for the CERN Intersecting Storage Rings¹²⁾, in order to extend such a miniature gauge's working range to below 10^{-13} torr.

6. ACKNOWLEDGEMENT

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According to the manufacturer, the gain of the CEM decreases by a
factor of two during a bake-out at 400°C for 16 hours. This figure
is, unfortunately, rather optimistic and seems to be correct for a
temperature of 300°C or less.
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TABLE I

Results from ion tracing computations for different initial conditions. The table gives the normalized deflector voltage $-U_d/U_g$ for which an ion is extracted to the CEM (col. 5) or impinges at either one of the collimator plates (col. 6). The different cases as denoted in col. 1 are drawn in Fig. 3, they are defined by the ions initial radial position r_o , when it leaves the collimator and by the horizontal and azimuthal angles of its initial direction, α and β .

	r_o / mm	α	β	Extraction	Collimator outer edge	Collimator inner edge
A	15.0	17°	0°	2.10 - 2.11	2.12	2.13
B	15.0	0°	0°	1.34 - 1.41	1.49 - 1.63	1.89 - 2.08
C	13.5	0°	0°	1.25 - 1.32	1.59 - 1.73	2.08 - 2.51
D	12.0	0°	0°	1.10 - 1.26	1.69 - 1.90	2.39 - 3.12
E	12.0	8.5°	180°	0.72 - 0.88	1.64 - 1.82	2.01
F	12.0	17°	180°	0.39 - 0.53	1.44	1.47

TABLE II

Operation parameters

Anode potential U_g	+ 130 V	+ 700 V (degas.)
Cathode potential U_f	+ 10 V	+ 50 V (degas.)
Deflector potential U_d	- 90 V	0 V (degas.)
(For x-ray background)	+ 130 V	
CEM cathode potential U_k	- 2.2... - 3.5 kV	0 V (degas.)
Emission current I_e	less than 5 mA typically $I_e = 10^{-17}/p$ (torr) A but less than $I_{e, \text{max}} = 3 \times 10^{-14}/p$ (torr) A to prevent CEM saturation.	100 mA (degas.)
Sensitivity S	about 10^{17} counts/s.A.torr for N_2	
x-ray background	6×10^3 counts/s.A.	

Figure captions

- Fig. 1 Photograph of the deflected beam gauge.
- Fig. 2 Schematic cutaway drawing (approximately at scale).
- Fig. 3 Illustration of some initial ion paths as listed in Table I.
- Fig. 4 Measured counting rate as a function of the normalized deflector potential $-U_d/U_g$. The horizontal bars denoted by A through F correspond to the range in which ions of different initial paths (see Fig. 3) are extracted to the CEM (left), or impinge at the inner or outer collimator edges (right).
- Fig. 5 Counting rate plotted against the emission current at different deflector potentials. The measurements were carried out at $p = 2 \times 10^{-12}$ torr.
- Fig. 6 Counting rate as a function of nitrogen and hydrogen pressure, indicated by a Helmer gauge. The deflected beam gauge was operated at 10^{-5} A emission current.
- Fig. 7 CEM electron collector current plotted against hydrogen pressure, measured by a quadrupole mass spectrometer. The curve has not yet been corrected for x-ray background.
- Fig. 8 CEM electron collector currents for ions, ($U_d = -90$ V with correction for x-rays) and for x-rays ($U_d + 90$ V) together with the ratio of both as a function of the CEM cathode potential U_k , at $p = 5 \times 10^{-12}$ torr and with 10 mA emission.

Fig. 1

Fig. 3

Fig. 4

Fig. 5

Fig.

Fig. 7

Fig. 6