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the effect of exposure to helium on photomultiplier performance and lifetime

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introduction

Photomultipliers have a finite lifetime depending primarily on the way in which they are used. It is known, for example, that multiplier gain changes as charge is drawn, particularly at high currents, but there is another less well known phenomenon which leads to reduced lifetime. Gases, particularly helium, can permeate the materials used for the envelope of vacuum devices, such as photomultipliers, whether they are operating or not. The purpose of this technical note is to quantify the effect of helium on photomultiplier lifetime at normal atmospheric concentration and at elevated concentrations found in certain applications. Although the effect cannot be entirely eliminated recommendations are given on the choice of envelope materials and on storage of photomultipliers that can lead to extended useful life.

Although chemically inert, ionised helium has a detrimental effect on photomultiplier performance. The major source of ionisation is the internal stream of electrons which constitute a photomultiplier signal. In practice, of the order of 0.01% to 1% of these electrons will collide with helium atoms, which may be present within the envelope, leaving some of them in an ionised state. Being positively charged, the ions are attracted to the nearest negative electrode where, upon impact, one or more electrons are released. Interactions that take place within the cathode to first dynode region are often most significant, because the electrons released here are multiplied in the same manner as a conventional signal. Consequently the initial signal and a satellite, known as an afterpulse, are observed at the anode, with a time separation in the range of 200 ns to 600 ns depending on the type of photomultiplier and on its operating conditions. The higher the voltages applied and the higher the multiplier gain the higher is the afterpulse rate.

theory

Permeation is the 'steady-state flow process from the gas phase on one side of a barrier (the glass envelope) to the gas phase on the other' (Norton, 1957). This is a seven-step process involving: impact, adsorption, dissociation, solution, diffusion, transfer, and desorption, as enunciated and illustrated in Norton's figure 1.

The quantity of gas permeating a material is given by

$$q = K A t (p_1 - p_2) / d \quad \dots(1)$$

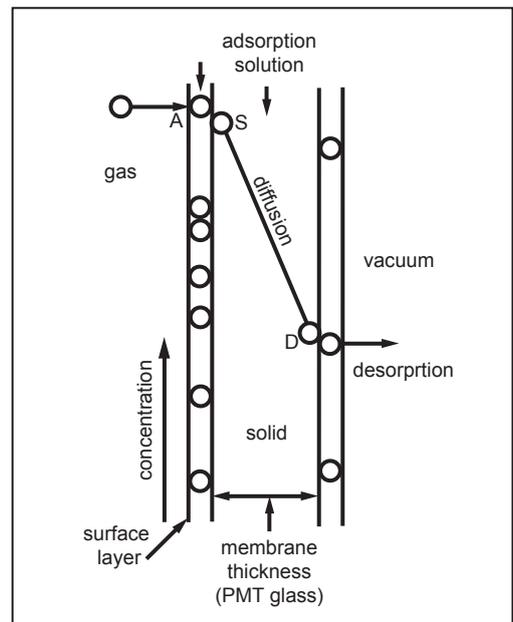


figure 1 steps in permeation process

where: K = the permeation velocity constant
 A = surface area of the exposed vacuum envelope
 t = the elapsed time
 p_1 = external partial pressure of gas species
 p_2 = internal partial pressure on the vacuum side
 d = thickness of the barrier

We note in (1) that q reduces as the pressure difference reduces. Although K is termed a constant it is in fact a reciprocal function of temperature with a magnitude determined by the envelope material. Experimental results of Norton (1957) are given in figure 2 for a range of glass materials, which are in close agreement with those presented by Altemose (1961). The relationship between the permeation velocity constant, K , and temperature is given by

$$K = A \exp(-Q/RT) \quad \dots(2)$$

where A is a constant, Q is the activation energy and R the gas constant. Applying this to the experimental results of Norton, we have for fused silica

$$K = 4 \times 10^{-7} \exp(-2.5 \times 1000/T). \quad \dots(3)$$

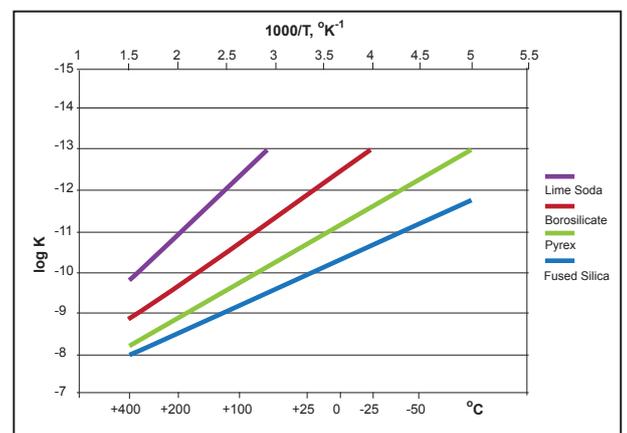


figure 2 experimental results for various materials used for photomultiplier envelopes.

Using the equation at normal temperature allows the elimination of q in (1) by using $p_{int} = q/V$. This leads to the following relationship between the increase in the partial pressure of helium as a function of time.

$$p_{int} = Ctp_{ext} / (1 + Ct) \quad \dots(4)$$

where: $C = 76 \text{ K A}/(d V)$.

Note that for small t (4) becomes

$$p_{int} = Ctp_{ext} \quad \dots(5)$$

and this linear dependence is evident for many decades of t in figures 3a and 3b following.

It is known from studies made on photomultipliers, which are activated but still connected to a vacuum station, that afterpulses will begin to appear at around 10^{-3} torr. The onset of severe afterpulse behaviour portends the approaching end of a photomultiplier, because once the pressure attains 10^{-2} torr the device begins to act as a light source leading to irreversible electrical breakdown. This not only corrupts measurements, but poses a threat to all but the least sensitive electronics.

two cases are illustrated

The figures show the effect of helium diffusion through the photomultiplier envelope, for the principle glass types used in photomultiplier manufacture (see below for definitions). They also indicate when significant degradation of performance, and ultimately failure, are likely to occur.

The material thicknesses and evacuated volume of a 9266 photomultiplier have been assumed for the purpose of calculation.

figure 3a The external pressure is equal to the normal atmospheric partial pressure of helium (5×10^{-6} atmospheres).

figure 3b The external pressure is 1 atmosphere of pure helium, a situation sometimes found in experiments where an inert environment is desirable. In such environments argon would be a better choice of an inert gas as the molecular size is bigger and the associated permeation rate is many orders of magnitude lower than helium.

glass types used in photomultipliers

fused silica: These glasses are close to 100% silica (SiO_2) such as spectrosil[®] 2000, Corning 7940 or equivalent

pyrex[®]: Although technically a borosilicate glass, pyrex[®] has a lower boric oxide (B_2O_3) content than those referred to as borosilicate in this report, such as Corning 7740, Schott 8330 or equivalent.

borosilicate: Higher boric oxide content glasses such as Corning 7052, Schott 8250 or equivalent.

lime soda: These glasses have CaO and increased Na_2O content place of B_2O_3 , such as Schott AR-GLAS[®] or equivalent.

rise in pressure versus time

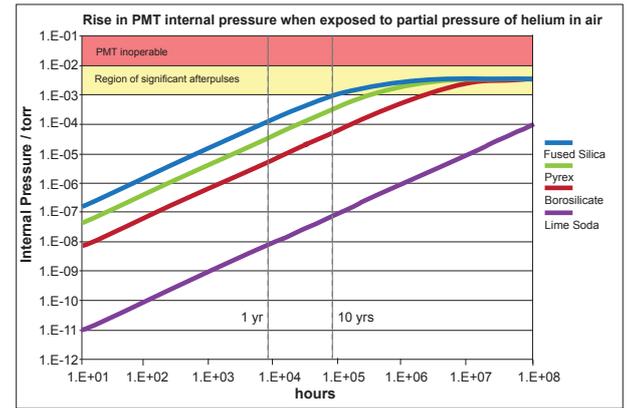


figure 3a rise in a 9266 PMT internal pressure when exposed to the partial pressure of helium in air.

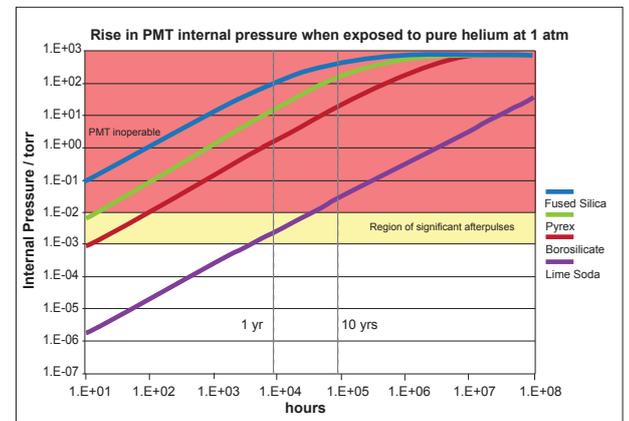


figure 3b rise in a 9266 PMT internal pressure when exposed to pure helium at 1 atmosphere.

time scales

t_{ap} time to the creation of significant afterpulses at an internal pressure of 1×10^{-3} torr.

t_{end} time to failure at an internal pressure of 1×10^{-2} torr.

| External He P / atm | 5×10^{-6} | 5×10^{-6} | 1 | 1 |
|---------------------|--------------------|--------------------|----------|-----------|
| glass type | t_{ap} | t_{end} | t_{ap} | t_{end} |
| fused silica | 8 years | - | 17 min | 3 hours |
| pyrex [®] | 30 years | - | 60 min | 10 hours |
| borosilicate | 230 years | - | 7 hours | 70 hours |
| lime soda | 144 000 years | - | 190 days | 3 years |

(Pressure unit conversion:

$1 \text{ atm} = 1.01325 \text{ bar} = 1.01325 \times 10^5 \text{ Pa} = 760 \text{ torr}$)

conclusions and recommendations

Helium permeation is not a serious issue for photomultipliers at normal air concentration. Where exposure to helium at elevated partial pressures is expected photomultipliers made with lime soda glass should be chosen.

suggested precautions at elevated external helium pressures

From (2), or from figure 2, we note that reducing the temperature from +25 °C to -25 °C reduces K by a factor of five. The obvious precaution is to store photomultiplier with a quartz envelope at low temperature when not in use.

Norton provides limited information on K values for other gasses but at 700 °C. Hydrogen has a permeation velocity constant some ten times lower than helium, but there is no information on the slope of the curve at room temperature. K is $\sim 10^{-15}$ for argon and nitrogen making them obvious candidates where gas flushing is feasible .

notes on the calculations

All calculations are based on a photomultiplier with dimensions identical to a type 9266; 51 mm (2") diameter, 100 mm long device. The differing thickness of window, tubing, and base have been taken into account. With the exception of fused silica the calculation assumes all the glass is of one type. For the option of a fused silica window and front section of tubing the graded seal has been taken to have an average permeation coefficient similar to pyrex[®] and the rest of the glass similar to borosilicate.

There is an initial delay upon exposure to helium pressure greater than the standard atmospheric partial pressure for the helium to first diffuse through the envelope. This delay is not included in the above calculations.

references

- 1) ET Enterprises Limited (2011) *Understanding Photomultipliers*.
- 2) V. O. Altemose (1961) (Corning Glass Works), *Helium Diffusion through Glass*, *Journal of Applied Physics*, Vol 32 No 7.
- 3) F. J. Norton (1957) *Permeation of Gasses through Solids* *Journal of Applied Physics*, Vol 28 No 1.

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