Photoelectron extraction efficiency from a CsI photocathode and THGEM operation in He−CF_4 and He−CH_4 mixtures

Jinst

Published by IOP Publishing for Sissa Medialab

Received: *January 12, 2016*
Accepted: *February 13, 2016*
Published: *March 21, 2016*

Photoelectron extraction efficiency from a CsI photocathode and THGEM operation in He-CF_4 and He-CH_4 mixtures

A.E.C. Coimbra,[a,1] **I. Israelashvili**[b,c,2] **and J.M.F. dos Santos**[a]

[a] *LIBPhys, Department of Physics, University of Coimbra, Rua Larga, Coimbra, PT3004-516 Portugal*
[b] *Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, 76100 Israel*
[c] *Nuclear Research Center of the Negev, P.O.B. 9001, Beer Sheva, 84190 Israel*

E-mail: Aeccoimbra@gian.fis.uc.pt

Abstract: This work presents the experimental measurements obtained for UV-induced photo-electron extraction efficiency from a CsI photocathode into He with CF_4 and CH_4 gas mixtures. A 1000Å CsI photocathode was deposited on a gold plated THGEM for photo-electron conversion. Charge-gain measurements were obtained with a Single-THGEM detector operating in these gas mixtures using a continuous UV lamp for the extraction of photo-electrons. Charge-gains in excess of 10^5 were obtained for gas mixtures containing percentages of quencher higher than 20% while photo-electron extraction efficiency achieved ~50% for He/CF_4 and ~30% for He/CH_4. Single photon electron measurements were also performed to assess the maximal gains reached in this regime. A discussion for future GPM cryogenic applications is presented.

Keywords: Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Electron multipliers (gas); Charge transport and multiplication in gas

[1] Corresponding author.
[2] Equal contributor.

doi:10.1088/1748-0221/11/03/P03025

2016 JINST 11 P03025

Contents

2016 JINST 11 P03025

1 Introduction

In previous works we have carried out an extensive program for the study of the collection efficiency of photoelectrons emitted by CsI photocathodes operating in gaseous atmospheres, noble gases and Ne-based mixtures [1–5]. Compared to vacuum operation, the emitted photoelectrons may collide with the gas molecules and return to the photocathode. The effective quantum efficiency is, thus, reduced when the photocathode is operated inside a gas atmosphere. Therefore, the photoelectron collection efficiency is an important parameter to consider when deciding about the suitability of a gas.

The photoelectron collection efficiencies present high values in molecular gases, around 90%, since the photoelectron loses almost all its energy in non-elastic collisions with the molecule, transferring energy for rotational and vibrational states of the molecule, and will not have enough energy to overcome the electric field and return to the photocathode, upon a collision. On the other hand, for the monoatomic molecules of the noble gases only elastic collisions are allowed and the photoelectron will retain its energy to get back to the photocathode, upon collisions, resulting in poor photoelectron collection efficiency [3]. Therefore, the addition of a molecular gas will increase the photoelectron collection efficiency in the noble gas [1, 3].

He-based mixtures may present a good alternative to Ne-based mixtures for the potential higher gains [6], with lower applied voltages, similar photoelectron extraction efficiency and lower costs. The THGEM operation in Ne-CH_4 and -CF_4 mixtures have been extensively investigated [4–10], but the studies of He-based mixtures for THGEMs have not yet been done. To the best of our knowledge, only [6] have presented a single test with such mixture, referring to its potential advantages.

In this work we present experimental measurements on the extraction efficiencies of photoelectrons emitted by CsI photocathodes operating in He-based mixtures and investigate the charge gain characteristics of THGEMs operating in He-based mixtures. The obtained results are compared with those obtained for Ne-based mixtures and a discussion on the potential use of He-based mixtures for future cryogenic applications will be presented. Main interest of these studies is related with the development of gas photomultipliers (GPM) for high-energy physics applications as an alternative to Ne-based mixtures, namely RICH detectors, e.g. [5, 11, 12], as well as for cryogenic applications, e.g. [6, 8, 13].

2 Electron scattering cross-sections

In figure 1 the electron scattering cross sections in He, CF_4 and CH_4 as taken from various authors is shown, highlighting the elastic momentum transfer as well as the inelastic momentum transfers, due to dissociative and electronic excitations, ionizations and vibrational excitations [14]. As seen, inelastic collisions of electrons with CF_4 and CH_4 molecules, due to the vibrational states of the molecules become important for electron energies above or around 0.1 eV, decreasing the probability of photoelectron backscattering to the photocathode in He-CF_4 and -CH_4 mixtures, when compared to a pure He atmosphere. He presents higher elastic scattering cross sections when compared to Ne (e.g. see [3]), indicating that He-based mixtures may need higher concentrations of molecular additives to achieve the same photoelectron collection efficiencies.

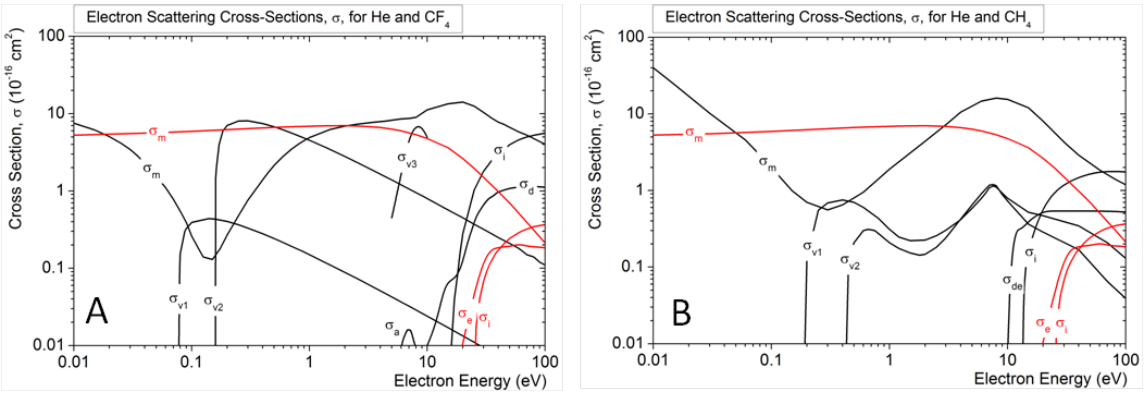

Figure 1. Electron scattering cross-sections in a) He (red) and CF_4 (black) and b) He (red) and CH_4 (black), from various authors [14]: elastic momentum transfer (σ_m), rotational excitation (σ_{rot}), vibrational excitation (σ_v), neutral dissociation (σ_d) dissociative excitation (σ_{de}) electronic excitation (σ_e), and ionization (σ_i).

3 Setups and methodologies

In this experimental work we used a single THGEM produced from G-10 with 0.4mm thickness and with a 0.02mm copper clad on both sides. It had an hexagonal pattern of holes 0.3mm in diameter, with a pitch of 1mm over an active area of 20mm x 20mm; the holes had 0.05 wide chemically etched rims.

The THGEM was assembled in the experimental system described in detail in [10]. The detector was assembled inside a cylindrical stainless steel vessel evacuated down to 10^{-5}mbar prior

2016 JINST 11 P03025

to gas filling. The THGEM and the drift stainless-steel mesh (50 μm thick wires and with 500 μm pitch) and the copper induction plane were assembled on Teflon mountings. The drift and induction regions were 6mm, and 2.3mm respectively, as shown in figure 2. The chamber was closed after gas filling and gas purity was maintained by circulation via convection through SAES St 707 non-evaporable getters, heated to ~120^{o}C. The filling gases were purified by gas circulation through SAES St 707 getters.

3.1 Charge-gain measurements

3.1.1 Current mode

Figure 2 depicts the experimental setup used for the effective gain determination. A 1000Å CsI photocathode was deposited on a gold plated THGEM for photo-electron conversion.

Charge-gain measurements were obtained with a Single-THGEM detector operating in these gas mixtures using a UV lamp for the extraction of photo-electrons. Photoelectrons were extracted from the CsI film by incident 185 nm VUV photons emitted by an Oriel Hg(Ar) VUV lamp and are focused into the THGEM holes, due to the strong electric field present in vicinity of the holes. The THGEM gain was obtained from the ratio between the current measured in the induction electrode after multiplication in the THGEM's holes (using the setup presented in figure 2) and the photocurrent extracted from the photocathode to the mesh above it without gas multiplication (as measured with the setup presented in figure 4).

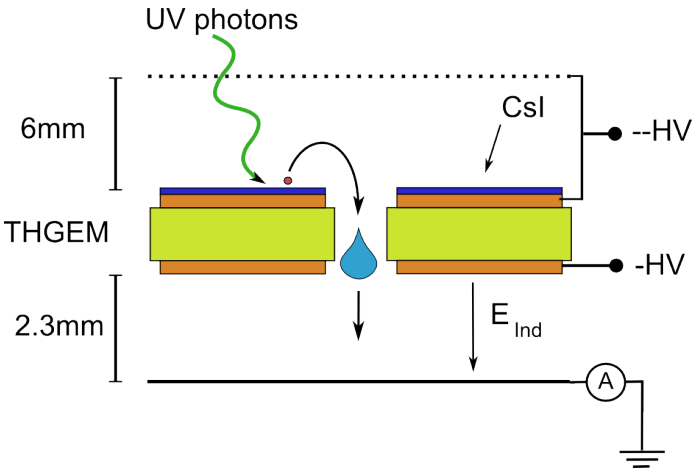

Figure 2. Schematic of the experimental setup used for effective gain determination, highlighting applied bias, the CsI photocathode and the THGEM used.

3.1.2 Single photoelectrons

In figure 3 the experimental setup used for single photoelectron measurements is depicted. In a separate chamber a single-THGEM detector was installed, where the CsI photocathode is removed from the top surface of the THGEM, leaving the bare gold deposited on the electrode exposed. The gold on the surface of the electrode acts a low efficiency photocathode (QE_{Au}(185nm) ~ 4×10^{-4} electrons/absorbed photon [15]), allowing the use of the continuous Oriel Hg(Ar) VUV lamp for single photoelectron studies using additional attenuators. For spectrum acquisition, the event rate

2016 JINST 11 P03025

was reduced down to tens of Hz allowing the use of a charge sensitive preamplifier (Canberra model 2006), followed by an Ortec 572A linear amplifier and an Amptek 8000D multichannel analyzer. A continuous flow of a He-CH_4(80:20) mixture was introduced in the detector at a flow rate of 100sccm/min during the measurements at atmospheric pressure.

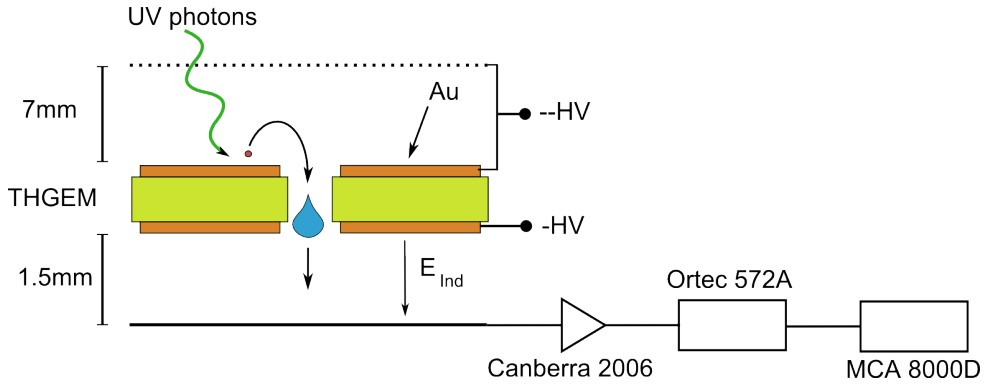

Figure 3. Schematic of the experimental setup used for pulse mode measurements with single-photoelectrons.

3.2 Photoelectron-extraction efficiency

In figure 4 we present the experimental setup used for extraction efficiency determination. Photoelectrons were extracted from the CsI film by incident 185 nm VUV photons emitted by an Oriel Hg(Ar) VUV lamp and are collected in the mesh placed above the photocathode. The photoelectron currents where measured operating the photocathode in vacuum and in the gas, being the measured photoelectron currents in gas normalized to the vacuum photoelectron current, as measured from the CsI photocathode as the ratio of I_{gas}/I_{vacuum}. This parameter is measured for the different He-CF_4 and He-CH_4 mixtures as a function of the electric field applied in the region above the photocathode.

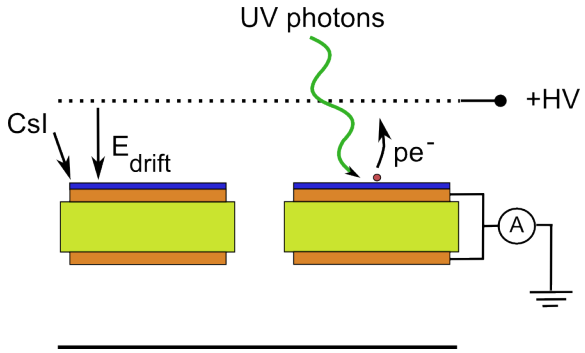

Figure 4. Schematic of the experimental setup used for extraction efficiency determination.

4 Results

4.1 Charge-gain determination

In figure 5 the obtained gain curves, measured in current mode, are represented for a single-THGEM + CsI photocathode deposited on its top electrode, operated under different He/CF_4 and He/CH_4

mixtures. The effective gain is represented as a function of the voltage difference applied to the THGEM electrodes.

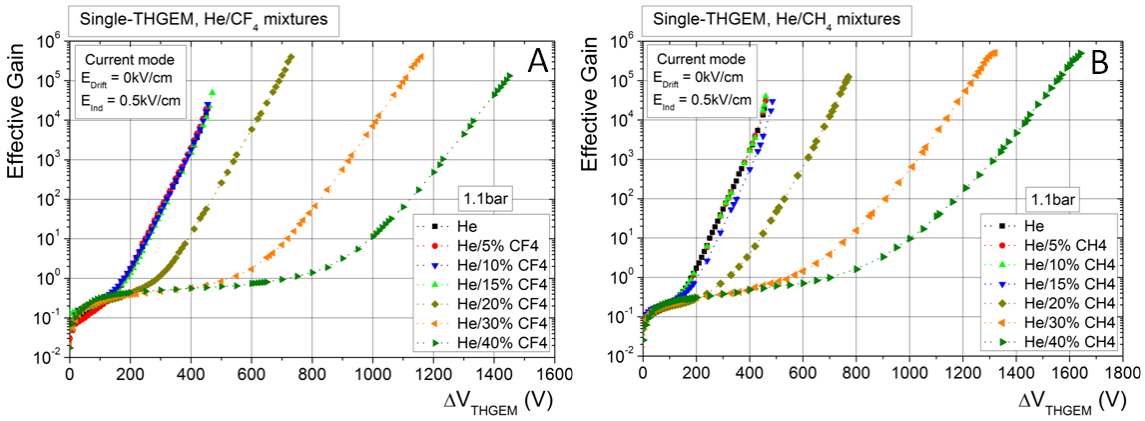

Figure 5. Single-THGEM gain-voltage curves, measured in current mode of photoelectrons emitted from a CsI photocathode coating the THGEM top electrode, for the THGEM operating under several He/CF_4 (figure a) and He/CH_4 (figure b) mixtures.

As seen from figure 5, both types of gas mixtures allow reaching very high charge-gains, well above 10^5. Similar gains are obtained in both types of He-based mixtures but higher molecular content and higher voltages are necessary for the He-CH_4 mixtures: maximum gains are obtained for CF_4 content around the 20–30% while for CH_4 the content must be above 30%. This trend and the achieved gains are similar to those obtained for Ne-based mixtures for THGEMs with similar parameters, e.g. [4, 5]; the differences in the maximum applied voltages needed in the different publications may result from different levels of gas purity, as demonstrated in [4] and [9]. On the other hand, when compared to Ar-based mixtures [4, 5, 11, 12], He-based mixtures allow to achieve similar gains but needing much lower voltages applied to the THGEM. Previous works [4, 7, 11, 12] have shown that the maximum gains achieved in pulse mode, resulting from interactions of X-rays with energies in the keV range, are lower than those achieved in current mode, by a factor that can be up to one order of magnitude.

Figure 6 shows a typical single photoelectron pulse height distribution for the maximum voltage applied before the occurrence of discharges, fitted by an exponential, obtained in a He-CH_4(80:20) mixture. From the exponential fit it was determined that the average value of the pulse height distribution corresponds to a charge of $\sim$ 8fC, translating to a single photoelectron gain of $\sim 5\times10^4$ — approximately a factor of two lower than in current mode measurements.

4.2 Photoelectron extraction efficiency

In figure 7 the measured photoelectron extraction efficiency from CsI into He and CF_4 mixtures are presented as a function of the electric field above the photocathode. In figure 8 similar results are presented for He and CH_4 mixtures. The measured photoelectron currents in gas were normalized to the vacuum photoelectron current as measured from the CsI photocathode, i.e. the ratio of I_{gas}/I_{vacuum}.

As shown from figure 7 and figure 8, the addition of CF_4 to He is more effective than the addition of CH_4, in terms of the reduction of photoelectron backscattering, the same behavior as that found

2016 JINST 11 P03025

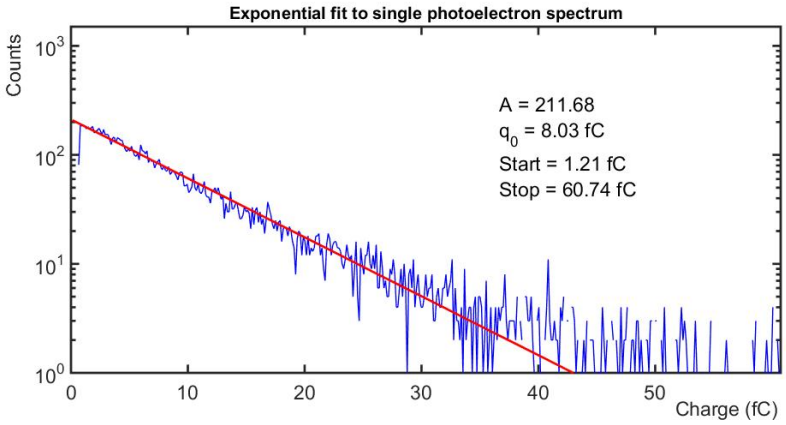

Figure 6. Typical single photoelectron pulse height distribution obtained in He-CH_4(80:20) at a charge gain of $\sim 5 \times 10^4$. "Start" and "stop" represent the region fitted to exponential, "A" and q_0 is the average charge of the single photoelectron pulse height distribution.

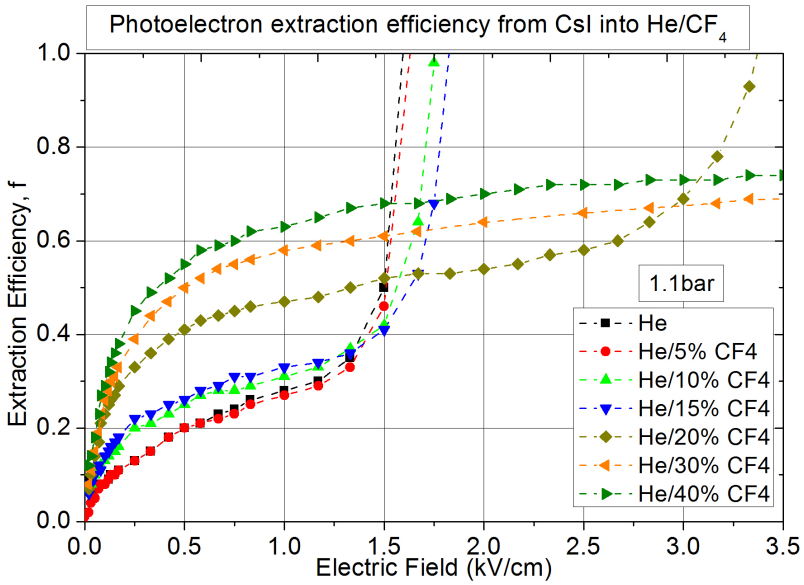

Figure 7. Photoelectron extraction efficiency from CsI into several He and CF_4 gas mixtures as a function of the applied electric field in the region above the photocathode. UV photons peaking at 185nm from a Hg(Ar) VUV lamp were used.

in Ne-based mixtures [3–5]. This is due to the fact that CF_4 presents lower energy thresholds for the vibrational excitations, resulting in the onset of inelastic collisions at lower photoelectron energies. However, more important is the fact that He-based mixtures present lower photoelectron extraction efficiencies than the Ne-base mixtures with the same molecular additive content. This is a consequence of the higher cross section presented by He for electron impact elastic collisions when compared to Ne. While for He-30%CH_4 mixture the photoelectron extraction efficiency is below 50% for electric fields lower than 2 kV/cm, in Ne-20%CH_4 it is already above 70% for electric fields above 1 kV/cm [3, 4].

2016 JINST 11 P03025

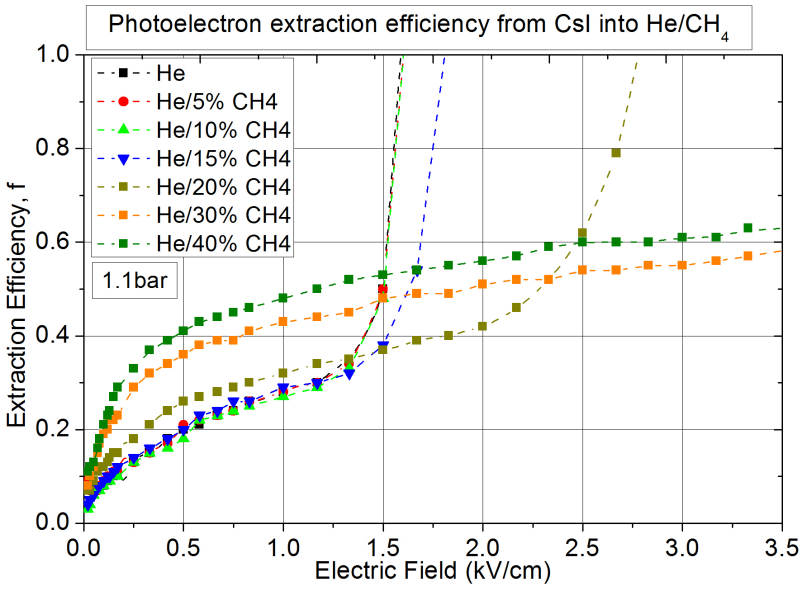

Figure 8. Photoelectron extraction efficiency from CsI into several He and CH_4 gas mixtures as a function of the applied electric field in the region above the photocathode. UV photons peaking at 185nm from a Hg(Ar) VUV lamp were used.

5 Discussion and conclusions

In this work a single-THGEM detector was operated in He/CF_4 and He/CH_4 mixtures reaching effective charge-gains well above 10^5, measured in current mode. These gains are similar to those obtained with Ne/CF_4 and Ne/CH_4 in current mode and with THGEMs having similar geometric parameters. Both types of gas mixtures (He and Ne) allow reaching very high charge-gains, applying relatively low voltages when compared to Ar mixtures.

The maximal achievable charge-gains for photo-electrons, in He-based mixtures are reached for higher molecular additive concentration when compared to Ne-based mixtures, namely ~20% for CF_4 and ~30% for CH_4.

Photo-electron extraction efficiency in He/CF_4 mixtures is high, reaching ~70% (He-40%CF_4) for a 2kV/cm electric field on the surface of the photocathode, while for He/CH_4 gas mixtures the photo-electron extraction efficiency is roughly 55% (He-40%CH_4). On the other hand, in Ne gas mixtures with CF_4 and CH_4, the photo-electron extraction efficiency can reach 80% for CF_4 or CH_4 concentrations as low as 10%. This is a consequence of the higher cross section presented by He for electron impact elastic collisions when compared to Ne.

In terms of photoelectron extraction there seems to be no advantage of He-based gas mixtures over Ne-based ones, being the only exception the reduced cost of He.

The well-known higher permeability of He through different materials, particularly through fused silica (a typical VUV transparent material used in GPM and vacuum PMT windows) when compared to that of other noble gases is, however, significantly reduced in cryogenic temperatures as shown by the permeation rate, K, given in units of cm^3 gas (N.T.P.) per second per cm^2 per mm thickness of material per unit pressure difference as a function of 1/T, represented in figure 9 [16].

2016 JINST 11 P03025

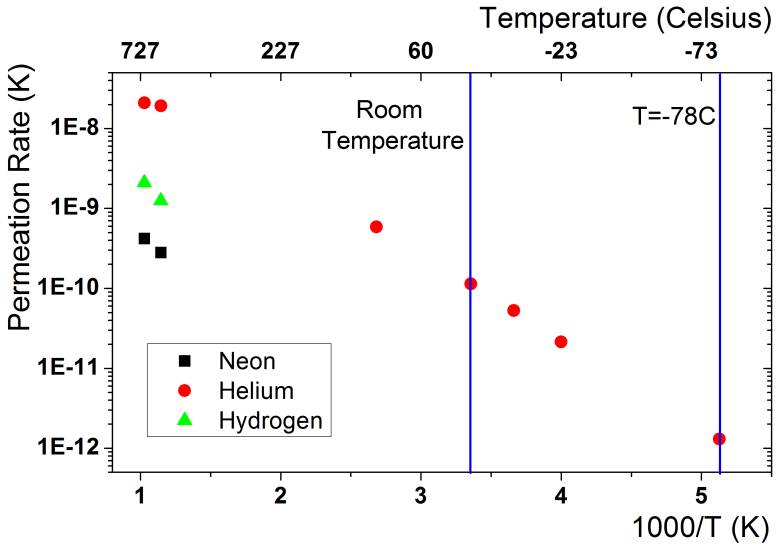

Figure 9. Permeation rate, K, of helium, neon and hydrogen through fused silica at various temperatures.

This feature, combined with the promising results previously shown, opens the possibility of using He-based gas mixtures in cryogenic VUV gas photomultipliers.

Acknowledgments

Support is acknowledged to FCT and EU-FEDER, under COMPETE program, through project CERN/123614/2011.

References

[1] L.C.C. Coelho et al., *Measurement of the photoelectron-collection efficiency in noble gases and methane*, *Nucl. Instrum. Meth.* **A 581** (2007) 190.

[2] L.C.C. Coelho et al., *Photoelectron transmission efficiency in Ar–CH_4 and Xe–CH_4 mixtures: Experimental results*, *Nucl. Instrum. Meth.* **A 607** (2009) 587.

[3] J. Escada, L.C.C. Coelho, T.H.V.T. Dias, J.A.M. Lopes, J.M.F. dos Santos and A. Breskin, *Measurements of photoelectron extraction efficiency from CsI into mixtures of Ne with CH_4, CF_4, CO_2 and N_2*, 2009 *JINST* **4** P11025 [arXiv:0909.2965].

[4] M. Cortesi et al., *THGEM operation in Ne and Ne/CH_4*, 2009 *JINST* **4** P08001 [arXiv:0905.2916].

[5] C.D.R. Azevedo et al., *Towards THGEM UV-photon detectors for RICH: On single-photon detection efficiency in Ne/CH_4 and Ne/CF_4*, 2010 *JINST* **5** P01002 [arXiv:0909.5357].

[6] S. Duval et al., *Hybrid Multi Micropattern Gaseous Photomultiplier for detection of liquid-xenon scintillation*, *Nucl. Instrum. Meth.* **A 695** (2012) 163 [arXiv:1110.6053].

[7] A. Breskin et al., *CsI-THGEM gaseous photomultipliers for RICH and noble-liquid detectors*, *Nucl. Instrum. Meth.* **A 639** (2011) 117 [arXiv:1009.5883].

[8] A. Breskin et al., *The THGEM: A thick robust gaseous electron multiplier for radiation detectors*, *Nucl. Instrum. Meth.* **A 623** (2010) 132.

2016 JINST 11 P03025

[9] A.E.C. Coimbra, A. Breskin and J.M.F. dos Santos, *THGEM operation in high pressure Ne/CF_4*, 2012 *JINST* **7** C02062.

[10] A.E.C. Coimbra et al., *First results with THGEM followed by submillimetric multiplying gap*, 2013 *JINST* **8** P06004.

[11] M. Alexeev et al., *THGEM based photon detector for Cherenkov imaging applications*, *Nucl. Instrum. Meth.* **A 617** (2010) 396.

[12] M. Alexeev et al., *Development of THGEM-based photon detectors for Cherenkov Imaging Counters*, 2010 *JINST* **5** P03009.

[13] L. Arazi et al., *First results of a large-area cryogenic gaseous photomultiplier coupled to a dual-phase liquid xenon TPC*, 2015 *JINST* **10** P10020 [arXiv:1508.00410].

[14] *IST-Lisbon and Bordage database*, www.lxcat.net, (2014).

[15] W.F. Krolikowski and W.E. Spicer, *Photoemission studies of the noble metals. II. Gold*, *Phys. Rev.* **B 1** (1970) 478.

[16] F.J. Norton, *Helium diffusion through glass*, *J. Am. Ceram. Soc.* **36** (1953) 90.

2016 JINST 11 P03025