Development of an Impurity Model for Large Liquid Xenon Detectors

Ako Jamil on behalf of the nEXO collaboration

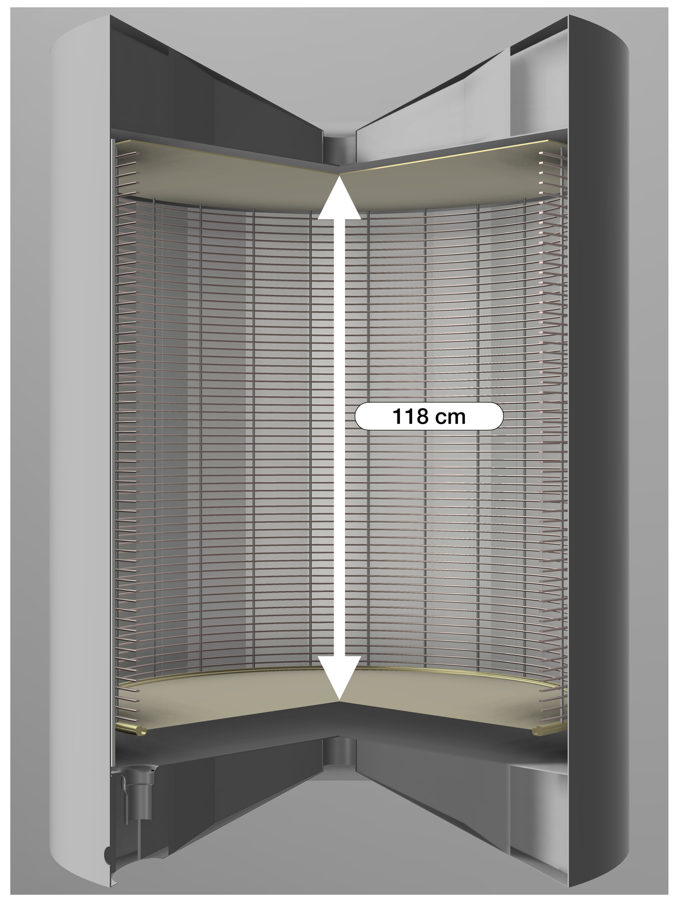
Wright Laboratory, Yale University (ako.jamil@yale.edu)

MOTIVATION

- Meter-long drift length in LXe requires high electron lifetime which is related to concentration of electro-negative impurities in liquid xenon via [1]

$$\tau = \sum_I \frac{1}{k_I \cdot [S_I]}$$

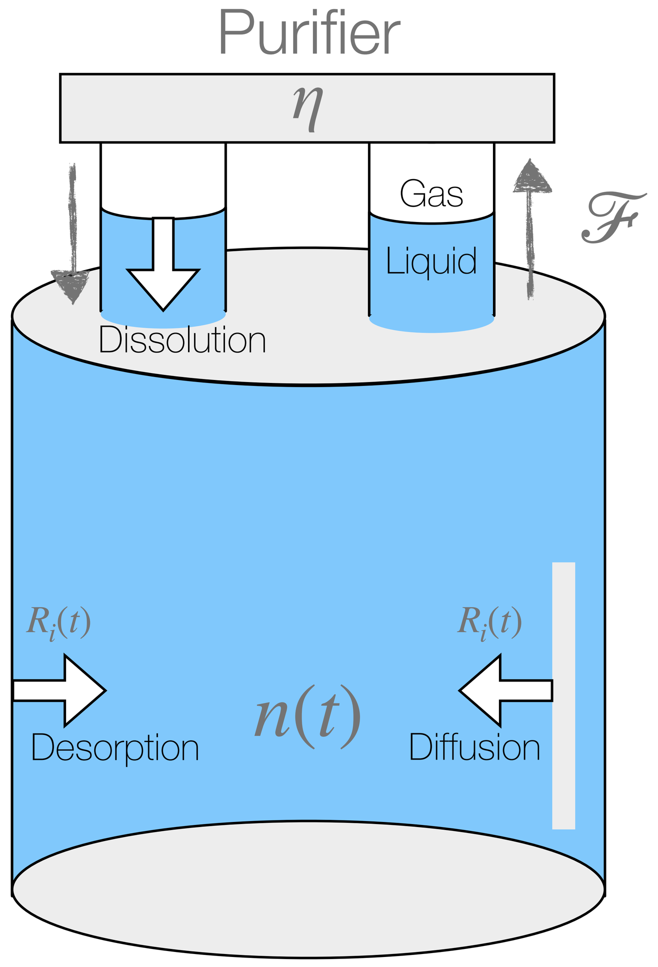
k_I = electron attachement cross-section
$[S_I]$ = concentration of impurity I



- nEXO aims for an electron lifetime of $10\,\mathrm{ms}$ [2]
- Here we measure underlying parameters needed to develop a empirical purity model for nEXO

IMPURITY MODEL

- Goal for an empirically driven impurity model:
  - qualify materials to be used in the detector
  - predict the expected electron lifetime
- Model parameters need to be measured experimentally
  - Intrinsic outgassing rate of materials at 165 K
  - Ratio of concentration of molecule in gas and liquid phase (Henry's coefficient $H_{I,\mathrm{LXe}}$)
  - Electron attachment cross-section k_I of impurities



Schematic of how impurities could be added to and removed from the LXe in nEXO

- **Given a purification system, how large of a outgassing rate $R(t)$ is tolerable while still maintaining an electron lifetime of $10\,\mathrm{ms}$?**

MEASUREMENT OF D_0 AND E_a

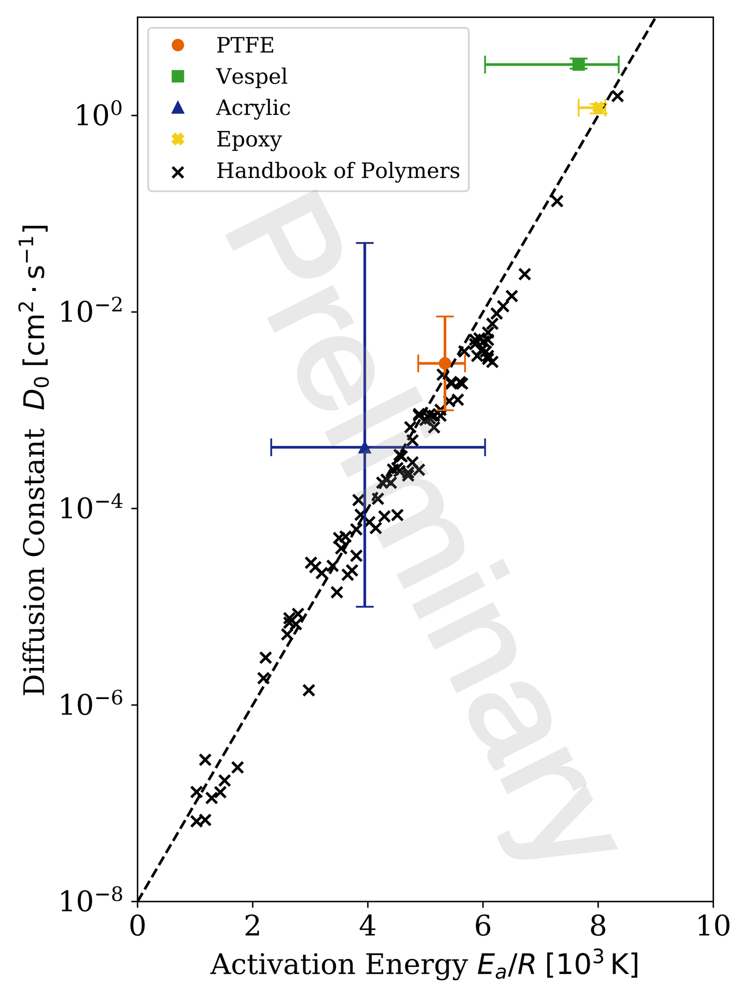
- Atmospheric gases dissolve into materials (i.e. plastics) and are released under vacuum
- The outgassing rate of a slab of thickness d can be written as [3]

$$J(t) \approx D(T) \cdot \exp\left(-\frac{D(T)}{d^2}t\right)$$

- The diffusion constant is linked to activation energy via the Arrhenius equation

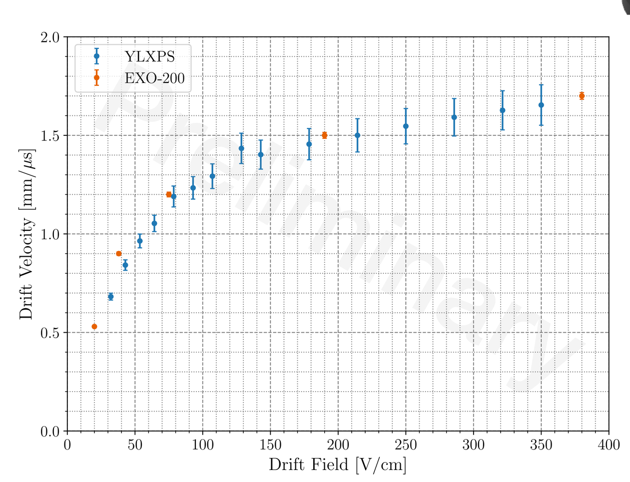
$$D(T) = D_0 \cdot e^{-\frac{E_a}{k_B T}}$$

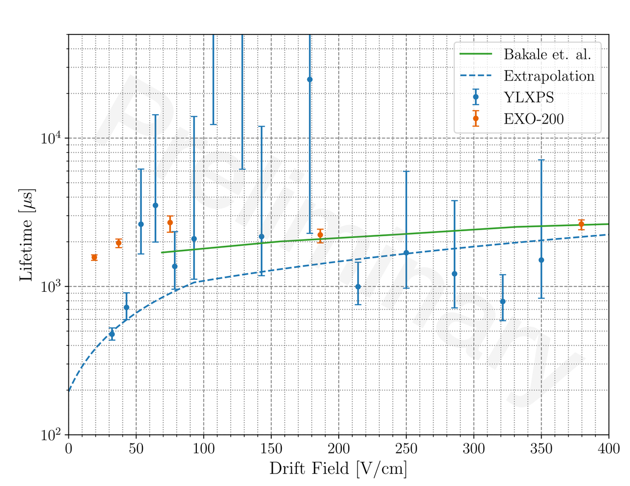
- Results are in good agreement with literature values of various elastomers and polymers

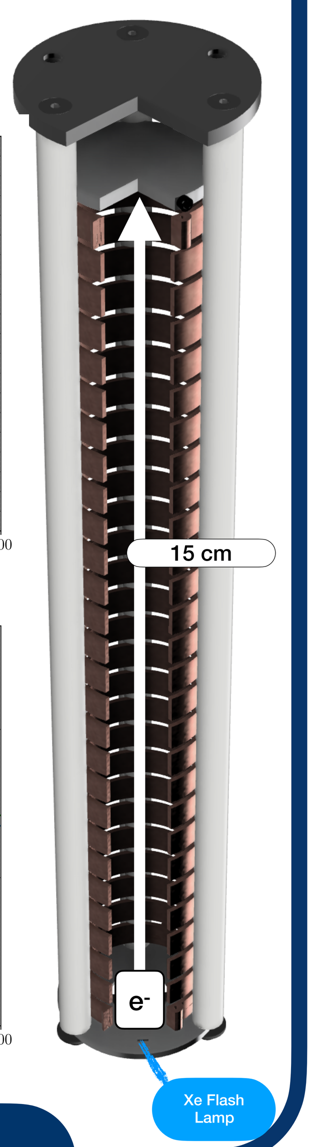


LIQUID XENON PURITY SYSTEM

- Unclear what impurity sources are limiting the electron lifetime in liquid xenon detectors
- Need in-situ measurements in LXe to determine contribution of different
  - Outgassing processes
  - Impurity species
- Key features of our LXe purity system:
  - No plastics (low intrinsic outgassing)
  - Continuous purification through SAES purifier possible
  - Cold-trap enhanced RGA-system allows to measure impurity concentration of $\sim 10^{-10}$
- Able to achieve lifetimes of $\tau > 1\,\mathrm{ms}$ (systematics limited)





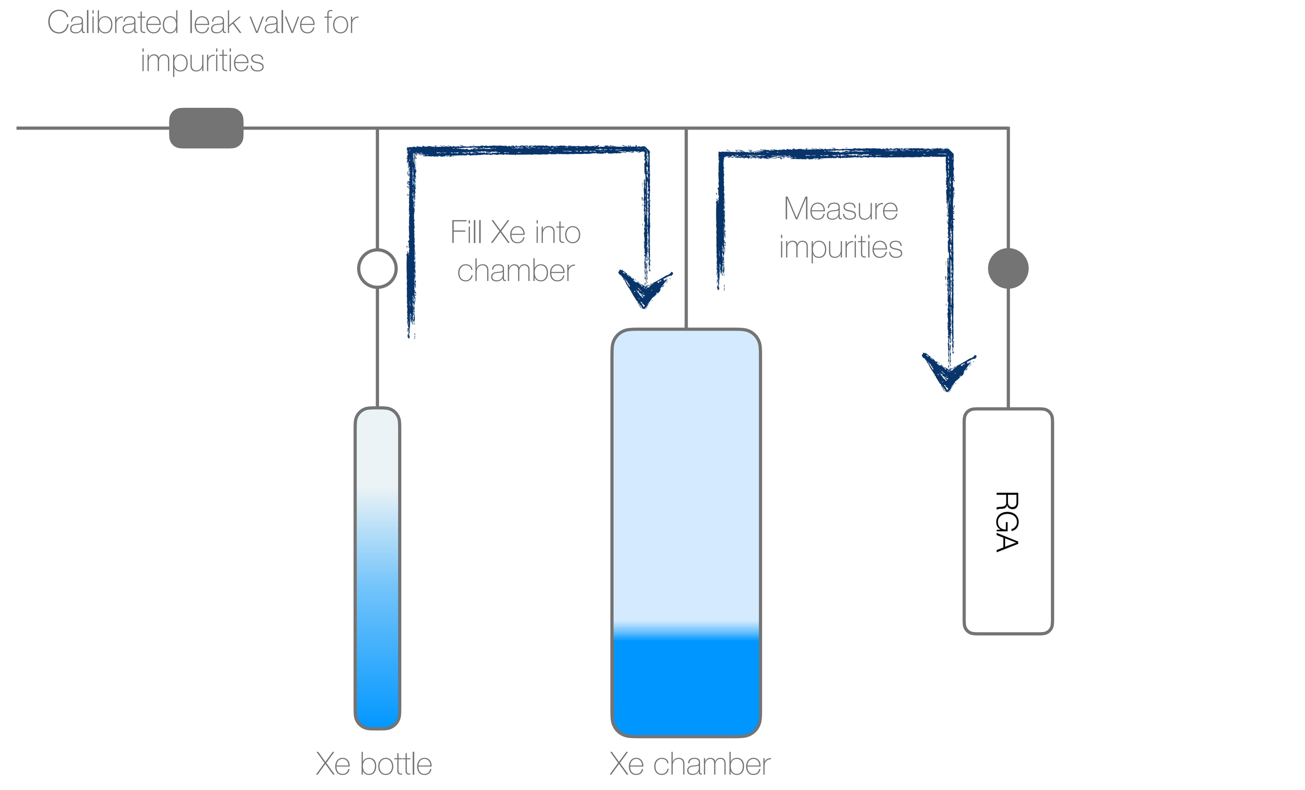


REFERENCES

(1) G. Bakale, et al (1981), DOI: 10.1515/zna-1981-0804
(2) S. Al Kharusi, et al (2018) arXiv:1805.11142
(3) John Crank (1975), The mathematics of diffusion
(4) A. Jamil (2020), APS April Meeting, link

SOLUBILITY OF OXYGEN IN LXE

- Simplified Procedure:
  - Fill known amount of impurities into system
  - As more liquid xenon is filled some impurities will dissolve
- Impurity concentration in the gas phase decreases as more liquid is filled and more impurities dissolve into LXe



- Repeated measurements yield consistent result:

$$H_{\mathrm{O_2,LXe}} = \frac{c_{\mathrm{I,gas}}}{c_{\mathrm{I,liquid}}} = 59 \pm 14 \qquad \text{(preliminary)}$$

- **First measurement of Henry's coefficient for oxygen in LXe!**
- Agrees with simple ideal gas behavior (ratio of partial pressures of oxygen and xenon at 165K)
- Future work will measure $H_{I,\mathrm{LXe}}$ for other electronegative impurities such as $N_2, CO_2, \ldots$