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Editorial: Fundamentals of luminescence and electroluminescence in particle detection technologies relying on noble-gas media

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Editorial on the Research Topic

Fundamentals of luminescence and electroluminescence in particle detection technologies relying on noble-gas media

Radiation detectors based on noble gas/liquid scintillation are at the core of particle physics investigations in areas such as dark matter searches, neutrino physics, and low-background rare event detection. Modern requirements are pushing the detector performance toward single-electron detection thresholds, Fano-limited energy resolution, topological information down to the thermal diffusion limit, gaseous wavelength-shifting and multi-wavelength detection. The detection media have the role of both scintillation and charge collection. The goal of the present Research Topic is collating the state-of-the-art into a unified reference work. It deals with conventional VUV-electroluminescence, but new experimental horizons are explored in the infrared range, gaseous wavelength-shifting, and use of molecular additives to reduce electron diffusion. They blend well with the contributions on microscopic and phenomenological transport modelling in this Research Topic and provide foundations to harness these phenomena. Three remarkable applications, in the dark matter detection and neutrino physics domains, and a novel idea for an all-liquid positron emission tomograph are presented here for the first time. The high-quality contributions in this Research Topic cover the entire electroluminescence field in the context of its application to radiation detectors and are expected to be a cornerstone in seeding technological innovation through improved detection concepts and ideas.

This Research Topic is aiming at a multi-faceted audience. Experimentalists require an up-to-date reference on light emission in the VUV-to-near-IR range, including light yield, spectra, excimer lifetimes, scintillation time profiles, and instrumentation details. Theoreticians will find information on the basic physical processes responsible for charge production and collection, and light emission in dense media, which are at the base of the detector performance.

Boyle et al. present a review of current experimental and theoretical data on electron transport in noble liquids, leading to a deep understanding of the basic electron scattering mechanisms in dense environments. They connect electron transport to scintillation, and mark a roadmap to accurate microscopic simulations of electroluminescence in liquid media.

Szydagis et al. provide a discussion of the simulation of the basic interactions in liquid Xenon searching for rare interactions stemming from new physics. The Noble Element Simulation Technique (NEST), a technique for phenomenologically modelling light and charge production, is reviewed in Xenon phase, compared with other models, and validated against experimental data.

Boltnev and Khmelenko propose an innovative concept of a three-phase TPC filled with Neon-Nitrogen nanoclusters in superfluid Helium for detecting light dark matter particles. Several assumptions require a concerted experimental effort or full elucidation, but the proposal represents an outstanding concept in this rapidly growing research field.

Hamman et al. report for the first time the time-resolved infrared scintillation of a dual-phase Xenon detector, showing that it improves signal identification and background rejection in future dark matter experiments. They put this idea on a firm experimental base, though it certainly needs further work.

Additionally, the features of the infrared emission due to the decay of highly-excited Xe excimers produced by electron impact in noble gases doped with significant amounts of Xenon are reported by Borghesani et al.. The authors show that the IR excimer band is red-shifted with increasing density by an amount that depends on the Xe concentration in the mixture because of the classical dielectric screening of the Coulomb electron-ionic core interaction and by the density-dependent quantum shift of the optically active electron.

A new methodology to measure electron transport and electroluminescence in Xenon-based detectors is reported by Henriques et al.. They precisely determine, in a unified experimental architecture, observables such as the Fano and Q-factors, scintillation and attachment probabilities, electron drift velocity and diffusion, giving special attention to the influence of molecular additives. This approach leads to a very good agreement between electron transport measurements and simulations. Remarkably, the scintillation probability of the gas is accurately described through a microscopic model developed by the team. This paper can guide researchers in the choice of the optimal molecular additive in rare-events detection experiment.

The properties of primary and secondary scintillation spectra in the range 200–800 nm in CF₄-based Helium and Argon mixtures at low pressure are investigated by Brunbauer et al., using a MicroPattern Gaseous Detector. They found that the primary scintillation spectra are almost insensitive to gas pressure, whereas a strong variation with pressure of the ratio of ultraviolet-to-visible light emission is observed for secondary scintillation. They also observed that introduction of small amounts of SF₆ (aiming at negative-ion TPC readout) leads to a decrease of the light yield, that might be compensated by additional multiplication stages. The results inform on the optimum optical readout device or wavelength shifter for low pressure applications.

An innovative design of a device for Positron Emission Tomography (PET) is reported by Backues et al.. Field-enhanced electroluminescence in a monolithic liquid Xenon target converts ionization into photons collected by photomultipliers. MC

simulations are used to optimize the field-cage design to improve the efficiency of light collection. This approach proves the possibility to improve the performance against current PET technologies and paves the way to a first technical implementation.

Scaling the 1 ton dual-phase Argon ARIADNE TPC to a 20 ton detector (ARIADNE+) for future neutrino-scattering experiments is the Research Topic of the contribution by Lowe et al.. In particular, the paper describes the details of design, construction, and performance of large light readout planes containing 16 glass THick Gaseous Electron Multipliers (THGEMs). Reconstruction of cosmic muons is reported and a forecast on future developments.

This Research Topic of nine diversified papers contributes to existing experiments in noble-gas electroluminescence and pertaining technologies. It finds its greater value by merging together valuable contributions in related fields. They give insight into fundamental processes of ultraviolet, infrared and wavelength-shifted light emission, in pure noble gas or mixtures, clarify the mechanisms of charge production and transport in the detector media, explain the steps to scale some of these technologies to make them usable in real-life applications, and inform towards future improvements in the TPC design.

We are confident that this Research Topic of advanced papers provides an indispensable reference for the detector community.

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