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Energy, Sustainability and Environment (2)

Towards more Environment-friendly Particle Detectors

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Energy, Sustainability and Environment (2)

With the renaming of the section at the last general assembly (see p. 6), we adapt also the name of this article series. Its goal is still the same, to showcase examples of how physicists can contribute to the pressing topics of energy and sustainability.

Towards more Environment-friendly Particle Detectors

The following article portrays the three physicists Dario Stocco, Marnik Metting van Rijn, and Christian Franck (Institute for Power Systems & High Voltage Technology, ETH Zürich), and their research towards more environment-friendly electric power transmission equipment and high-energy particle detectors.

Dario, can you tell us a bit about you, why did you study physics, and when did you start to think about the topics of energy and sustainability?

Dario: It was in high school in Glarus, where my great physics teacher, Mrs. Gärtner, showed me the beauty of physics, recognized my potential, and ultimately helped me decide to pursue a career in physics. Having a basic understanding of physics made me realize early on that our behavior is not sustainable. So I'm glad I now get to do more than think about it – I get to contribute.

After completing your studies, you joined Sensirion Connected Solutions, where you developed models to quantify methane leaks for monitoring purposes. How did this experience inspire you to pursue a doctoral thesis on environmentally friendly gas mixtures?

Dario: Monitoring across the methane supply chain, including extraction sites, pipelines, and storage facilities, is a relatively new development. Until recently, it was largely unknown how much methane was being emitted, despite its global warming potential (GWP) being roughly 30 times greater than that of carbon dioxide [1]. The realistic models we developed demonstrated the severity of the actual emissions. Some sites had ongoing emissions of up to several tons of methane per month, corresponding to several hundreds of tons of CO_2 equivalent per month! But with proper monitoring and regulation, those emissions can be significantly reduced. From that experience, it was clear to me that I had to continue to work against these super emitters and harmful greenhouse gases.

Marnik, the same questions to you: Why did you study physics in the first place and why and how did you choose the topic of you doctoral thesis ?

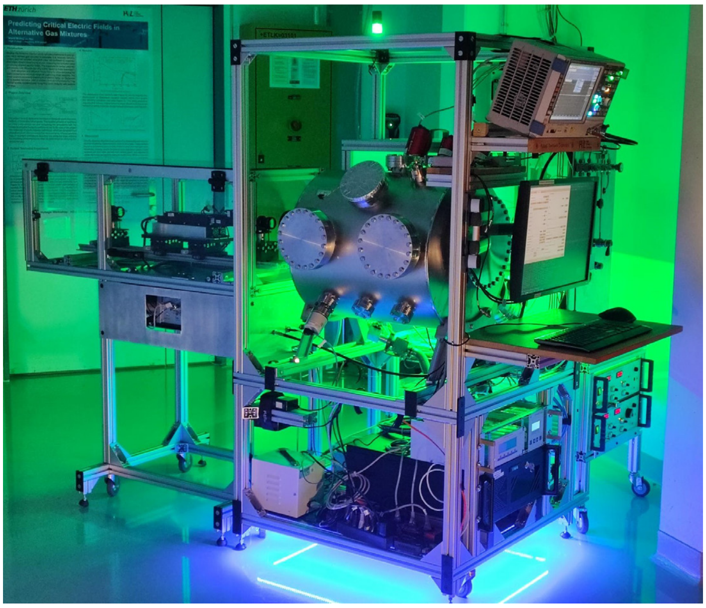
Marnik: I had the privilege to attend an extended physics course at K&S (MNG) Rämibühl, which helped me decide between physics and chemistry. In hindsight, it does not surprise me at all that I encountered difficulties in choosing between the two sciences: My doctoral thesis involves electron-molecule scattering cross sections and spectroscopy, both topics related to physical chemistry. Being able to combine these two fields is what persuaded me to choose my doctoral thesis.

You're both working on environmentally friendly gas mixtures for resistive plate chamber detectors (RPCs). Can you explain what the project involves and its sustainability impact?

Dario & Marnik: The presence of a high-energy particle, like muons, can be deduced if it interacts with matter, for example, a gas mixture. In RPCs, the particle of interest penetrates a gas volume and ionizes the gas molecules, leaving freely moving electrons behind. An applied electric field accelerates these electrons, which collide with other gas molecules. During the collision, the electrons further ionize these molecules. The number of electrons hence grows exponentially, and the generated electron avalanche induces a detectable signal. In essence, RPCs serve as fast, large-area amplifiers of ionization events. Unfortunately, the gas mixture currently in operation at CERN exhibits a high global warming potential of around 1500 and is responsible for a considerable 0.4% of Switzerland's total greenhouse gas emissions. We seek to find alternative gases that can drastically reduce environmental impact while ensuring adequate detector performance.

Why it matters?

Dario: Widely used fluorinated gases like the refrigerant R-134a or SF_6 and their derivatives are extremely potent greenhouse gases. Even small leaks from detectors or high-voltage equipment can accumulate to significant climate impact. Identifying and implementing low-GWP alternatives is critical for reducing long-term emissions in both science and industry.



The Pulsed Townsend Setup (© HVL – Marnik Metting van Rijn): A pulsed UV laser releases seed electrons into a gas-filled chamber between two electrodes, thus a uniform electric field drives the electrons across the gas. As the electrons travel, they collide with gas molecules; some are scattered, some ionize the gas, others attach to molecules. The resulting displacement current is measured over time to determine drift velocity, diffusion coefficients, ionization and attachment rates.

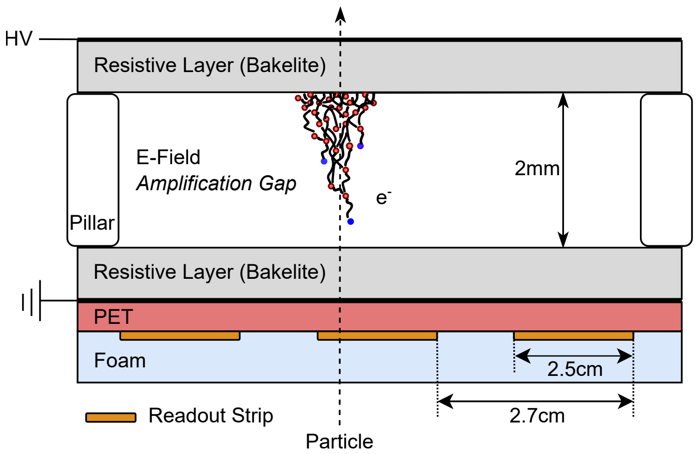
Marnik: We're working on identifying alternative gases that maintain detector performance but with significantly lower environmental impact. Monte Carlo simulations of the underlying stochastic processes provide guidance and predict optimal gas mixture concentrations. These simulations, however, require the electron-molecule scattering cross sections of each individual molecule in the mixture.

How do you obtain these cross sections?

Dario & Marnik: That's where our Pulsed Townsend experiment comes in. We measure transport parameters of electron swarms in gases - drift velocity, diffusion, ionization, attachment rates - and use those to extract the needed cross sections [2]. We are currently focusing on ultra-low GWP refrigerants, as they are already commercially available in quantities required by large-scale facilities such as CERN.

And these gases are also relevant for other applications, right?

Dario & Marnik: Exactly. The cross sections are also required for the development of high-voltage insulation equipment. Providing the electrical power industry with the cross sections of an environmentally friendly gas enables them to deploy it in the numerous substations part of the electrical grid, which will have a severe impact on sustainability.



A schematic plot of a RPC setup with schematic of avalanche (published as Figure 1 in https://doi.org/10.3929/ethz-b-000727665)

Christian, how was your journey of professional life and what does energy and sustainability mean to you?

Christian: That I wanted to study physics was clear to me already during Gymnasium. I attended the standard curriculum in the first year, but chose one additional course in my second year as its name "Die Energiefrage" (the question of energy) caught my attention. And it was the engaging and fascinating way Prof. Heinloth held the lecture that convinced me that I wanted to contribute to solve the energy and global warming problems. I took quite some detours and several attempts before I managed to get there, but in hindsight all these intermediate steps were helpful in one way or the other. The initial plan when changing to the University of Kiel was to study and research on renewable energy production, but it didn't work out and I specialized in plasma physics instead. With this I thought I could contribute by working in fusion and decided to pursue a PhD in Greifswald, where Wendelstein 7-X was build. However, I felt I wasn't patient enough to endure the long phase of construction and joined industry after graduating. Having applied to fuel-cell and lighting research positions as well, I decided to work with switching arcs and electrical insulation in electric power transmission equipment. Thus, I indirectly helped that more renewable energy can be integrated into the network and transmitted from the place of production to where it is consumed. When I was offered the position at ETH, I chose research topics in the area of more environmentally friendly and more sustainable power transmission equipment. We have projects to replace SF_6, with a GWP of 23500 one of the most potent greenhouse gases, from the transmission and distribution equipment and high-energy particle physics gas detectors, high-voltage direct current (HVDC) switchgear, overhead power lines and underground cables, as well as electric motor insulation. Even though these topics are by far not sufficient to solve all our problems, they have a non-negligible impact and I feel it's very fulfilling to work in this area.

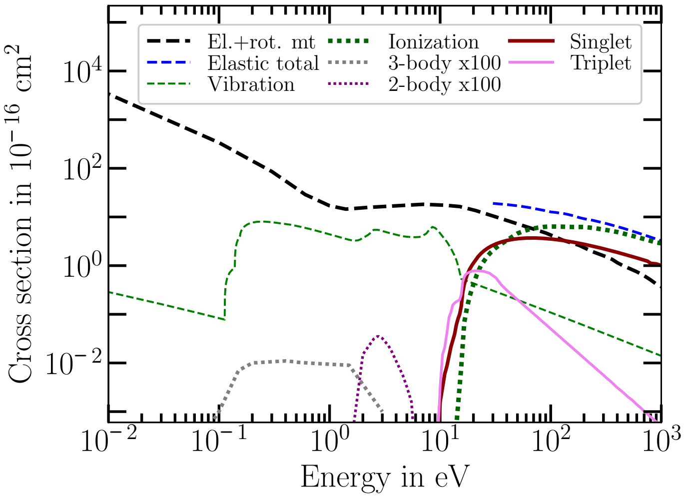
Dario and Marnik told us about their project. Can you tell us more about the other research projects in your group and in particular how physicists can contribute to them?

Christian: The field of power engineering in general, and that of high-voltage engineering in particular, is very interdisciplinary. Some of the innovations in the field were enabled by developments in other fields. When material science advanced with metal oxide varistors, the technology of surge arresters changed completely. Similarly, the improved basic understanding of switching arc physics has led to an almost complete dominance of self-blast breaker technology. In the research in my group we try to determine and quantitatively describe the basic underlying principles of processes involved in various gaseous and solid insulation technologies to enable fast and predictable development improvements. The replacement of greenhouse gases described by Dario and Marnik before is one example. Methods from atomic and molecular physics as well as physical chemistry are applied for a relevant application. The measurement and derivation of electron-molecule interactions are of help for gaseous particle detectors, but also for the development of SF_6 free gas insulated switchgear and improved dry etching and chemical vapor deposition processes. These are used in the semiconductor industry, chip manufacturing, or photovoltaic module production, to name only a few.

To understand also the processes in the solid insulation material of underground or subsea high-votlage direct current (HVDC) cables helps to improve the cable design and to increase the life-time in operation. We have just started a project to investigate the breakdown processes in dynamic export cables, those cables that deliver the power of hundreds of MW from floating windmills and converter platforms off-shore to the land. The unique combination of thermal, electrical, and mechanical stress require a very detailed understanding of the basic process that free charge carriers have in polymers, which eventually also lead to damage in the cross-linked bonds. In collaboration with electrical and mechanical engineers, as well as material scientists and chemists, physicists are ideally trained to reveal and describe fundamental processes, down to the scales where quantum mechanics matter.

You're educating and mentoring many students, what advice can you give them if they want to contribute to the transition of our society towards a greener way of living?

Christian: Studying an engineering discipline or natural sciences of course is an ideal basis for this. During your studies, you're exposed to a vast number of different topics and areas. It is not always easy to find those areas that attract you most and also have a short- to medium-term contribution to a more sustainable society. But being aware of this can help you to find your right area of specialization during studies and guide your job search afterwards. In engineering studies the link to industry is very close and natural, but after I had studied physics, the step into industry wasn't that obvious to me at the time. But I can only encourage every young physicist not to only think about working in governmental research centers (like I did initially), but also to explore the exciting world of industrial research and development. Applying your physics training for a meaningful application towards a more environmentally sustainable society is equally rewarding, if not more, than searching for the next elementary particle or the origin of our existence.



Set of electron scattering cross sections for R134a (published as figure 3 in https://doi.org/10.3929/ethz-b-000678002)

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