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Extended Abstract

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Counting individual ions by tagging them with nanoparticles

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The quantification of ultra-low concentrations of molecules and ions in gases is of fundamental and practical importance for science and technology, for example, the detection of explosives in airports or biomarkers in medical diagnostics. Often the Faraday cup is employed to transfer ion concentrations in an electric current that is then amplified and measured. One of the main challenges is to increase the sensitivity of detection. A novel concept has been developed that enables detection of individual ions in gases by tagging them with neutral nano-objects. The concentration of ionized molecules was measured and a detection limit of 5 cm -3 was observed. It is anticipated that this concept opens doors for advances in detection sensitivity for many applications including security, medical diagnostic, trace chemical analysis.

A novel concept of measuring the concentration of ionized molecules in gases that enables detection of individual ionized molecules by means of tagging them with readily detectable nanoobjects has been discovered. It was found that this method where ions were tagged with electrically neutral objects, e.g. nanoparticles with radius 100 nm, can provide a breakthrough in sensitivity by enabling a single ion or electron to be detected. This provides an increase in sensitivity by three order of magnitude in comparison to existing methods. This concept was termed Individual Ion Tagging (IIT).

Single ion detection is accomplished by employing a novel detection principle: tagging of ions. Instead of amplification of a weak electric signal from the Faraday cup here we enlarge every ion by attaching to it an electrically neutral tagging object or simply tag. This creates a mixture of electrically charged (by ions) tags and neutral tags. Charged tags containing ions then separated from the neutral tags with an electric field and counted individually by an Optical Particle Counter (OPC). To confirm the detection capability of the method a reference method is needed. Unfortunately, there are no methods available to generate and to quantify such low concentrations of ionized molecules in the air at which the IIT is capable of measuring (down to hundreds and tens of molecules per cm3). The detection capability of the IIT method was evaluated assuming that for ultra-low concentrations the ion losses are equal to losses for larger concentrations. The concentration measured in tests was down to hundreds of ionized molecules per cm3 , e.g. 560 per cm3 for acetone. A signal of 15 molecules per cm3 could be reliably detected with 3:1 signal noise ratio. The minimal detection level for this signal/noise level would be 15 molecules per cm3 . This is equivalent to measuring an electric current of the order of atto-amps that is practically impossible (or very difficult) at room temperatures with conventional methods. The IIT method is confirmed to be able to count individual ionized molecules. This is also sufficient to monitor VOC metabolites emitted by single cells and single cell bacteria making it potentially possible to detect cancer and other biomarkers at earlier stages. The IIT breakthrough in sensitivity of charge detection opens new horizons in many areas. For example, one such application of IIT could be detection of high energy cosmic ray particles with energy above 1016 eV. The cosmic ray flux for these energies is below 1 m -2 yr -1 . It is a challenge to detect these particles with conventional means. However, there are no physical limitations to building an IIT detector with the sensor area much greater than 1 m2 , e.g. up to 104 m 2 or even greater. This may help in finding the maximal energy of cosmic ray particles: the Greisen–Zatsepin– Kuzmin limit. The filter enables one to scan the ionmobility parameter and record mobility spectra as a function of the compensation voltage (CV). Therefore, only ions of chosen mobility could pass through the ion filter to the IIT set-up. With the ionization chamber and the ion filter, several molecules have been detected including cocaine, trinitrotoluene, iso-propanol and acetone. The latter two are typical VOC metabolites often found as in vivo and also in vitro samples and identified as possible biomarkers of some pathological conditions

It was found that the material of the external flask does not affect the counts. In addition, removal of radon from the air using clean nitrogen from a high-pressure cylinder does not affect the number of counts either. On the contrary, peaks and average background counts were influenced by the volume of the external flask. Therefore, it might be suggested that the counts observed in the clean air were associated with ions generated by cosmic rays ionizing air molecules in the external flask.

There is no reason why IIT could not be applied for detection of weakly interacting massive particles in environments where cosmic rays are not present such as deep underground mine laboratories. The origin of peaks of different height in cosmic ray tests is likely to be associated with the different energies of particles perhaps protons ionizing air molecules in the flask. Also it can be expected that different particles, e.g. protons, muons, electrons can generate different number of ions. Therefore, IIT can be employed to detect and possibly identify ionizing radiation for security and other applications. It is anticipated that this concept opens doors for advances in detection sensitivity in chemistry, biology, medicine and physics.

Bottom Note: *This work is partly presented at joint event on* 3rd International Conference on Nuclear and Plasma Physics & 4th International Conference on Quantum Physics and Quantum Technology, November 05-06, 2018, London, UK