Design status of the differentially pumped gas cell for Positive Ion Mass Spectrometry (PIMS)

N. Pandit[1]*, G.C. Wary[1], A. Barthakur[1], J.J. Das[1], M. Patgiri[1], D. Sarma[1], P.C. Rout[2], S. Santra[2], V.M. Datar[3], C.P. Safvan[4], B.K. Nayak[5], S. Ghugre[6]
[1]*Physics Department, Cotton University, Guwahati - 781001, INDIA*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA*
[3]*Institute of Mathematical sciences, Chennai - 600113, INDIA*
[4]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA*
[5]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, INDIA*
[6]*UGC DAE CSR Kolkata centre, Kolkata – 700098, INDIA*
. * *email: phy2091004_nabajyoti@cottonuniversity.ac.in*

Introduction: The CUPAC-NE (Cotton University Particle accelerator Centre and North East Collaboration) has proposed to construct a discovery class accelerator facility with (i) a 5 MV Van de Graff accelerator with an ECR ion source at the terminal and (ii) a PIMS accelerator which is also based on using an ECR ion source [1]. Both the accelerators will be first of its kind in the nation and will open up new and emerging frontiers of modern science.

Radio carbon dating using Accelerator Mass Spectrometry (AMS) technique has been in use for last several decades [2]. However, basic processes involved in the method: mechanical mixing of cathode during graphitization, inherent instability in beam transmission through the tandem and chemistry are not reproducible with required accuracy, which eventually limits the accuracy that can be obtained. These determine the limit of resolvable time window separating two samples which is ~200 years [Radiocarbon 62(2) 1-21) March 2020)]. PIMS is a new technique in which intense beam of $^{14}C^{+}$ isotopes from an ECR ion source is converted into negative $^{14}C^{--}$ ions by passing through a high pressure isobutene gas target in a differentially pumped cell. Interestingly $^{14}N^{+}$, the dominant isobaric contaminant does not form negative ions. A mass spectrometer downstream of the cell rejects $^{14}N^{+}$ ensuring pure $^{14}C^{--}$ are measured at the focal plane.

As PIMS is discovered only recently, very few investigations beyond proof of principle demonstrations were done so far. We plan to explore PIMS to verify some of our predictions: (i) It will be possible to achieve lower time resolution than AMS and (ii) PIMS will work with large number of isotopes as the fundamental physics of the process is very similar to the ones used in RIB injector at ORNL [4].

These predictions are based on our analysis that: (i) Direct use of CO_2 samples in ECR ensures high reproducibility with near zero memory effect. Thus, eliminates uncertainties of AMS process mentioned earlier and (ii) as only a single stage post acceleration of 40 to 100 kV is used in PIMS, high stability in transmission is easily achievable. In contrast, fluctuations in ion optics of large number of components due to stability of power supplies result in transmission uncertainties. Finally, an observation, even though AMS were run with CO_2 samples to get achieve superior reproducibility, an ECR source with CO_2 sample delivers >1mA current compared to ~100 µA obtained in AMS. With these ideas in mind, we are developing PIMS instrumentations to test these experimentally. Status of these will be presented in this paper.

Charge exchange cell design details:

The cell is a SS cylindrical cell with 2 pairs of conical apertures, a pair with 5 mm and another with 10 mm diameter. The use of two apertures ensure restricting conductance to obtain higher pressure for a given mass flow and aperture diameter. A practical advantage of this approach is, it allows using apertures of larger diameter which minimize chances of beam scattering from edges of the aperture. Two turbo pumps backed by an oil free scroll pump will be used for pumping the CEC (Refer to Fig. 1 for details).

The CEC will be placed inside a high vacuum chamber. Aluminum support stand with alignment screws will be used to ensure that beam passes through the central axis of the cell. Isobutane gas will be fed into the central compartment of CEC through a tygon tube. The pressures in vacuum chamber and CEC will be measured by using: capacitative manometer, cold cathode gauge and Pirani gauges.

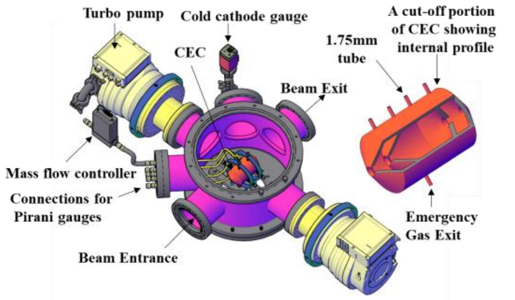

Fig 1: Vacuum chamber and pumping system of CEC

In the NEC system [Ref. NEC PIMS Handout], the isobutene gas flow rate is 1-10 sccm. The internal construction and process used in the CEC is not known (under patent). But the double aperture design reported here offers enough flexibility to obtain high pressure to obtain optimum charge exchange efficiencies.

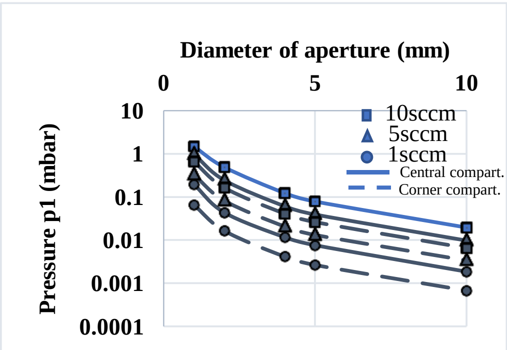

Fig 2: Pressure inside the central and outer compartments of the CEC for different flow. Calculations were done for 2 sets of apertures in entrance/exit with 5/10 mm diameters respectively.

Results: The pressures inside the CEC for isobutene gas for various conditions are shown in Fig. 2. These calculations were done using first principle methods of gas flow dynamics. The number density of isobutene atoms were calculated for different pressure ranges calculated for CEC are: central/outer compartment: $(3.68 \times 10^{16} – 2.4 \times 10^{14})/ (1.62 \times 10^{16} – 8.33 \times 10^{13})$ atoms/cm^3 respectively. For the CEC of 50 mm length, the Ariel target density is ~ 10^{15}-10^{16} atoms/cm^2. We think it should be adequate for the experiment.

Summary and discussions: We designed a multi-compartment differentially pumped CEC from scratch for PIMS research. Our design ensures both: operation at high pressure and minimum scattering of beam from the edge of apertures. There is an obvious concern here, whether the Ariel thickness obtained is adequate for the successful PIMS investigation? We don't have a direct answer.

Certainly, having estimates of the cross-section would have been very helpful but the atomic physicists of the country is not working in the successive 2-electron capture process involved in the PIMS and hence was unable to give us any estimates. However, our view is: The CEC design we described originated mainly from the long experience our group had in the field of advanced gas flow dynamics in ORNL/ NSCL. At this time, there is no evidence that such concepts are used in the patented PIMS CEC. If that indeed is the case, our design may prove to be superior to the NEC CEC design and may result in improved efficiencies for PIMS.

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