Pramana - J. Phys., Vol. 39, No. 5, November 1992, pp. L583-L587. © Printed in India.

A novel study of charged carbon clusters using a tandem Van de Graaff accelerator

V S RAMAMURTHY, D P MAHAPATRA, R T YADAV, G V RAVI PRASAD and ARJUN GOPALAKRISHNA
Institute of Physics, Bhubaneswar 751005, India

MS received 18 July 1992; revised 14 September 1992

Abstract. A conventional tandem Van de Graaff accelerator is used to produce charged carbon cluster beams. The unique capability of the method for studying highly charged clusters unaccessible to other methods of producing cluster beams is demonstrated.

Keywords. Charged carbon clusters; accelerator.

PACS Nos 41·75; 36·40

Clusters are interesting intermediates between matter in bulk and the constituent atoms. Studies of their structure and properties in the recent years have revealed that they cannot be obtained as trivial interpolations between the bulk properties and the atomic properties. Cluster properties also play an important role in the laboratory synthesis of materials and are therefore of technological importance. Traditional methods of cluster production for experimental investigations include laser ablation, nozzle expansion etc. which in general result in neutral clusters.

The Institute of Physics, Bhubaneswar has recently installed a 3 MV Pelletron accelerator. The layout of the essential components of the accelerator are shown schematically in figure 1. It is a horizontal tandem electrostatic accelerator model 9SDH-2 Pelletron supplied by NEC, USA. It is equipped with two negative ion sources λ: an RF charge exchange source and a cesium sputter ion source. While the RF source produces He^-, the cesium sputter source (SNICS) (Middleton 1989; Norton *et al* 1989) produces a wide variety of negative ions from solid materials. A stream of singly charged negative ions from either of the ion sources is accelerated to about 70 keV through a preaccelerating column and then enters into the injector magnet which sorts the ions by mass and directs them into the accelerating column. An Einzel lens operating at 60 kV focusses the beam into the accelerating column. At the middle of the accelerating column is the high voltage terminal, designed for a maximum terminal voltage of 3 MV. In the vicinity of the high voltage terminal a gas stripper is present which strips some of the electrons from the ions and makes them positively charged. Since they are now at a high potential they get 'pushed' towards the end of the accelerating column which lies at ground potential. A magnetic quadrupole doublet focusses the beam into the entrance slit of a high resolution analysing magnet which sorts the ions by energy and charge state. Faraday cups are being used to monitor the beam current at different locations. A quadrupole

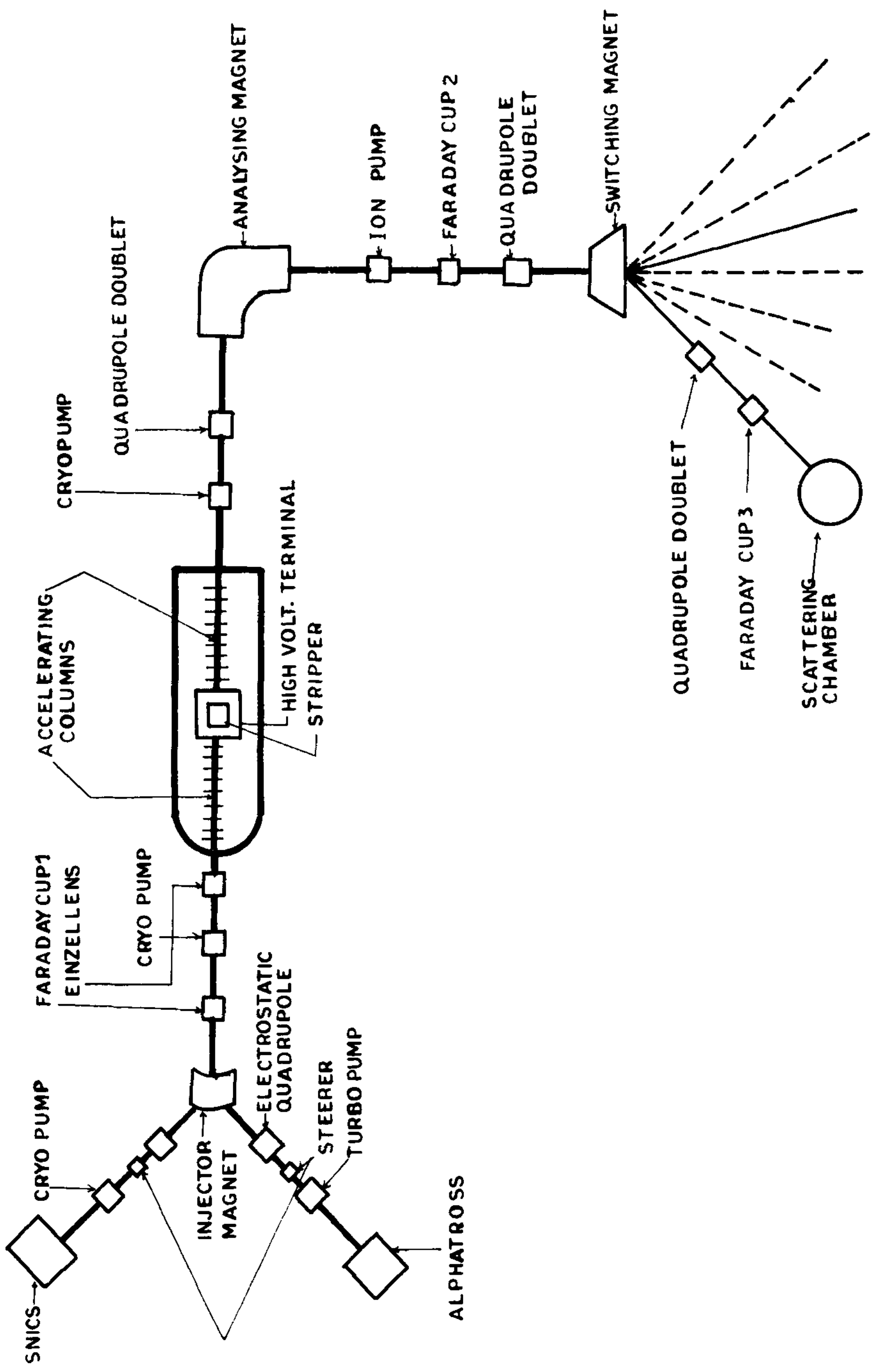

Figure 1. Schematic layout of the 3 MV pelletron accelerator.

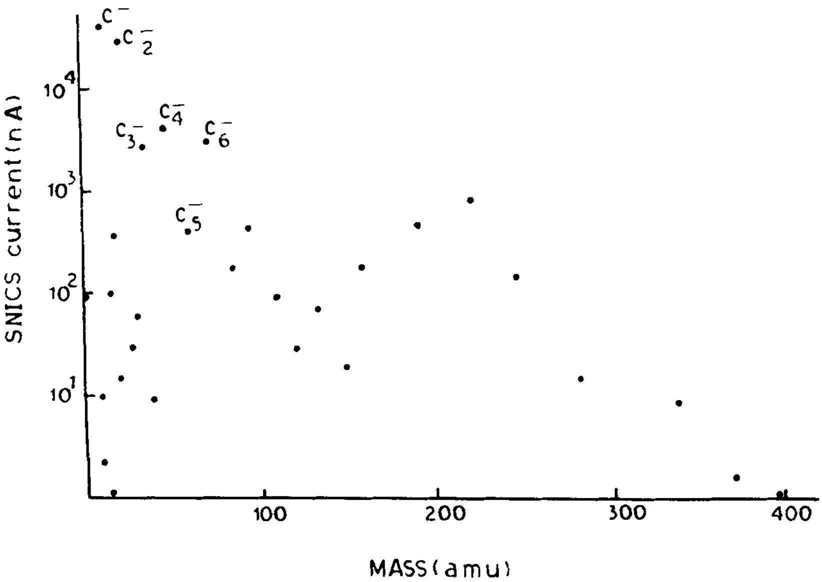

Figure 2. Negative ion current obtained from the SNICS source as a function of mass number.

doublet after analysing magnet focusses the beam into the switching magnet which finally puts the beam into the desired beam line.

It is known that SNICS sources are also prolific sources of composite clusters. Acceleration of these clusters in a tandem accelerator is generally hampered by the fact that these are broken at the stripper located in the high voltage terminal. We show here that by using low pressure gas stripping, it is possible to strip the cluster without breaking it, thus enabling acceleration of the cluster to MeV energies. For the present invesitigations, we use graphite as the cathode material in the ion source. The singly negatively charged carbon clusters from the SNICS are first accelerated to about 70 keV and then injected, after mass selection, into the accelerating region. Figure 2 shows a plot of the injector yield as a function of the mass of the cluster. It is seen that a variety of clusters are getting produced in the ion source and getting injected into the accelerator. The upper limit of mass about 400 seen in the figure is imposed by the bending power of the injector magnet and does not reflect the range of masses produced in the ion source. With a terminal voltage of V million volts these clusters are accelerated to energies of V MeV before stripping. At the centre of the accelerator, in a field-free region, a few electrons are stripped by a nitrogen gas stripper. To avoid disintegration of the cluster at the stripper, we operate the stripper at a very low pressure to ensure minimal multiple collisions. The gas pressure however has to be adequate to strip a few electrons. The positively charged clusters are further accelerated down the accelerator. The beam emerging out of the accelerator will in general consist of negative clusters of very low energy, neutral clusters, charged clusters of different charge states and disintegration products. In order to separate the different components, one can use the 90° analysing magnet to momentum analyse the beam. By sweeping the magnetic current, one can separate out clusters of different momenta. In the absence of the disintegration products, this amounts to separating clusters of given mass, energy and charge state. Since the final energy of an ion in a tandem accelerator depends on the charge state of the ion, disintegration products of a cluster in general interfere with the cluster if they have the same charge to mass ratio in the momentum analysis. To explain this further let us consider the case when C_6^- is injected into the machine at an injection voltage of 70 kV. Further, let us assume that while going through the stripper gas it breaks up into two C_3 clusters which can be produced in different charge states. With an applied terminal voltage of 1·1 MV, C_3^+ will come out with an energy which is 1·1 MeV plus half the energy gained up to the terminal that totals up to 1·685 MeV. At the same time a C_6^{2+} cluster also gets accelerated to a final energy of 3·370 MeV. Since ME/q^2 is the same for both cases magnetically they cannot be separted. Similarly charged clusters C_6^{6+}, C_5^{5+}, C_4^{4+}, C_3^{3+}, C_2^{2+} and C^+, if they are present, cannot be separated. There are many more examples of this.

Table 1 shows the yields of momentum analysed beams for different masses and charge states of observed clusters. It can easily be seen that sizable beams of singly charged carbon clusters with up to six carbon atoms are being produced. In the case of multiply charged clusters, in most cases where measurable beam currents have been recorded, contamination with dissociation products cannot be ruled out. In the other cases, the yields are below our detection limit, typically less than 1·0 nA. A close look at table 1 also indicates the following. There is practically no contribution corresponding to odd charge states for even atom clusters, the only exception being C_6^{13+}. In addition, the yields corresponding to three atom clusters are comparatively less than the other cases.

A very surprising result of the present study is the detection of C_6 clusters in the 13+ charge state. Such a highly stripped cluster will in general be expected to be unstable and disintegrate instantaneously at the stripper. The distance from stripper

Table 1. Yield of momentum analysed beams corresponding to different masses and charge states for various clusters.

C_2			C_3			C_4			C_5			C_6		
C_2^{m+}	A	B	C_3^{m+}	A	B	C_4^{m+}	A	B	C_5^{m+}	A	B	C_6^{m+}	A	B
C_2^+	7·8	62	C_3^+	1·9	10	C_4^+	3·0	20				C_6^+	2·0	10·0
C_2^{2+}	7·0	180	C_3^{2+}	1·9	1·0	C_4^{2+}	2·5	49				C_6^{2+}	2·3	110·0
			C_3^{3+}	1·9	20·0							C_6^{3+}	1·8	100·0
C_2^{4+}	8·9	265				C_4^{4+}	2·2	250				C_6^{4+}	1·8	1·7
									C_5^{5+}	0·2	5·0			
C_2^{6+}	7·0	2	C_3^{6+}	1·9	30·0							C_6^{6+}	1·8	75·0
						C_4^{8+}	2·1	65						
												C_6^{10+}	2·2	1·5
												C^{13+}	1·3	1·4

Double box entries are for cases where interference from disintegration products is not expected. A = The output current (μ − amp) of the SNICS source getting injected into accelerator; B = Current (nano-amp) after momentum analysis.

to Faraday cup 2 is about 12 m; and for ions of few MeV energy the time needed to traverse this distance is of the order of one micro-second. One can therefore conclude that typical life time of these ions are more than a micro-second. That we are able to obtain nano ampere beam of this cluster indicates that this cluster is quite long-lived and is profusely produced. It would be very interesting to study the structural and spectroscopic properties of this cluster in detail. Since we do not see any signature of C_3^{5+} even when a three atom cluster is selected at injection, the signal that appears for the case of C_6^{10+} which one might consider to be contaminated by C_3^{5+} may also be pure. It may be interesting to study this as well. Further investigations are in progress along these lines.

In summary, we have demonstrated that a conventional tandem Van de Graaff accelerator can be used to produce cluster ion beams in the MeV energy range. The method has unique advantages in studying high charge states usually unaccessible to other methods of cluster production.

We are thankful to the operating staff of the pelletron accelerator for their help in carrying out these studies.

References

Middleton Roy 1989 *A negative-ion cookbook* Int. Rep. of Physics Dept., Pennsylvania Univ, Philadelphia, USA

Norton G A, Daniel R E, Loger R L and Schroeder J B 1989 *Nucl. Instrum. Methods.* **B37/38** 403