ACCU-EBIS: Collection and Ionisation of Reaction Products

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Abstract

Rare reaction products from beam-target interactions can be accelerated at a low duty cycle for further nuclear characterisation by collection of these nuclei over seconds and ionisation to reasonable charge states using an EBIS that has conservative electron beam parameters. Trapping in the EBIS is performed by injecting singly charged ions over a barrier into an electron beam of sufficient density so that ionisation to a higher charge state occurs as the ions pass axially through the electron beam. Subsequent ionisation and extraction in a short pulse is then a standard EBIS technique. For extremely long collection and/or ionisation times, the trapped ions must be cooled by light ions.

1. INTRODUCTION

For the characterisation of exotic nuclei created in collisions of high energy particles with fixed targets, an acceleration of these ions to MeV/u is necessary [1]. The nuclei of these ions usually are created at a low rate, so their collection and ionisation to a high charge state allows them to be accelerated much more efficiently in a short pulse than by feeding them singly charged to a CW accelerator. An Electron Beam Ion Source (EBIS) utilised in a dedicated mode of operation is able to collect, trap and further ionise these ions to a reasonably high charge state. In this paper we will explain the basic features and the mode of operation for such an Accumulator-EBIS, which can be useful for the study of exotic nuclei.

2. TRAPPING OF IONS

The basic configuration for an ACCU-EBIS is similar to those EBIS sources which are used as injectors to accelerators [2,3] (see Fig. 1). The external ion source

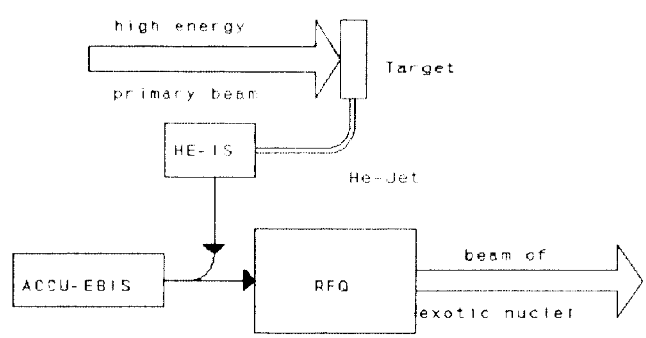

Figure 1. Schematic diagramme of the ACCU-EBIS operation

is typically a high efficiency (HE-IS) type [4] and must produce in a short time (ms) low energy ions of the exotic nuclei created in the target by the primary beam. These ions are accelerated by a DC potential of a few kV and transported to the axial access of an EBIS. The potentials along the electron beam are chosen to form an axial trap with different potentials on both ends. The energy of the injected ions must be high enough to overcome the entrance potential barrier, but low enough for the ions to be reflected at the other end of the trap. The travel time of the ions along the electron beam trap inside the beam must be long compared to the ionisation time from charge state 1 to charge state 2 (typically 1 μs for an electron beam of 100 A/cm²). The increase of the charge state makes it impossible for the ions to overcome the entrance potential barrier a second time (see Fig. 2), because for the same axial velocity, the retarding fields of the barrier potentials double for ions with doubled charge state. As ionisation to a higher charge states becomes possible, this kind of trapping scheme becomes more effective.

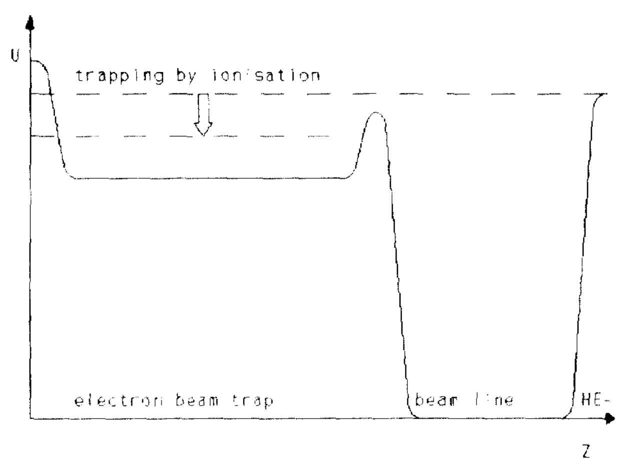

Figure 2. Axial potentials to trap ions by ionisation

This method of trapping is similar to the injection of ions into an EBIS from an external ion source, which is now a well established technique. The accumulation procedure can be continued, until a reasonable quantity of ions is trapped in the EBIS between the axial potential barriers. The applied trapping time must take into account the life time of the exotic nuclei.

3. IONISATION

In an EBIS, the charge state distribution depends on the time evolution of stepwise ionisation. This is shown in Table 1 for a relatively modest current density of 100 A/cm². Since the accelerator

Table 1
Charge states of representative ions produced by an electron beam of 100 A/cm² at 6 keV

Ion	10 ms	100 ms	1 s
C	5	6	6
Ne	8	9	10
Ar	13	16	17
Kr	21	29	33
Xe	28	40	43

into which the highly ionised ions must be injected is restricted to a certain charge to mass ratio, a wide range of acceptable ions and allowable ionisation times requires an adjustable electron beam density. This is possible for both immersed and Brillouin flow focusing by varying the magnetic field at the cathode of the electron gun. However the design of an electron gun to accomplish this requires detailed numerical simulations using proven tools, such as EGUN [5] and INTMAG [6], programmes for the calculation of electron guns and static magnetic fields.

4. ION HEATING AND COOLING

The trapped ions in the EBIS are heated by small angle Coulomb scattering of the beam electrons, resulting in radial ion losses and a large emittance for the extracted ion beam. It has been shown [7] that the radial energy is directly related to the ion charge state, independent of the electron beam current density, but varying with the electron beam energy. For the ion charge states of Table 1, these energies can be related to a radial holding voltage, as shown in Table 2.

Table 2
Radial holding voltage (V) of ions heated by 6 keV electrons of 100 A/cm^2 as function of time

Ion	10 ms	100 ms	1 s
C	0.32	1.32	13.2
Ne	0.44	3.34	11.4
Ar	0.76	4.02	24.6
Kr	0.86	8.19	43.7
Xe	0.87	14.30	29.2

For ions where the radial holding voltage exceeds approximately 1 V, a means of cooling must be provided. This is done by introducing cold ions into the ion trap, which cannot get highly charged, e.g. D, Li, or even C for cooling of heavy ions. Experience with both the EBIT trap device [8] and EBIS sources [9] has shown that cooling by neutral atoms works efficiently. Other cooling schemes have been proposed recently [10] but not yet tested experimentally.

5. ION EXTRACTION

Ion extraction from an EBIS is well established, with typical extraction times of 30 to 50 μs. For the further acceleration of the extracted ions in an RFQ it may be advantageous, however, to shorten this extraction time, as proposed for a light ion cancer treatment facility [11]. This requires the application of a continuous axial electrical gradient over the whole length of the ion trap. The advantage for the RFQ will then be that it can run at a very low duty cycle, removing the need for cooling and greatly simplifying its design.

6. CONCLUSION

Exotic nuclei produced in target interactions with high energy beams can be collected, trapped and ionised in an ACCU-EBIS to a reasonably high charge state. The application of this technique enables for simple acceleration to perform further characterisation of these nuclei. The dedicated EBIS will have conservative values of electron beam energy and current density.

7. REFERENCES

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