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The Belfast EBIT

Hirofumi Watanabe and Fred Currell[*]
Atomic and Molecular Research Division, Department of Physics,
Queen's University, Belfast, BT7 1NN, UK
(*)e-mail address: f.j.currell@qub.ac.uk

Abstract. A new Electron Beam Ion Trap has been designed for use at the Queen's University, Belfast. We describe our design, with particular reference to the machine's versatility and inclusion of new features which will make the machine particularly suited to the study of electron-ion interactions. An initial experimental program, making use of these features is described as is other information pertinent to potential collaborators.

INTRODUCTION

Electron-beam ion traps and sources (EBITs + EBISes) have been successfully used to study the physics of highly charged ions in a wide number of ways through the use of a high energy and current density electron beam which creates, traps and excites the ions under study [1,2]. Although similar in many respects, one generally accepted difference between these two types of device is the split-coil arrangement of EBITs which allows photons to leave the trap to travel through windows. Through detection of these photons one can perform spectroscopic studies. Furthermore, by using the yields of these photons it is possible to infer information regarding the various electron-ion interactions.

One recent trend in the development of EBITs has been the use of permanent magnets to provide lower cost sources [3, 4]. The highly charged ion group at Queen's University, Belfast are presently constructing a permanent magnet based EBIT, which additionally seeks to take advantage of opportunities offered by the permanent magnet structure. Several of these new features make the device particularly suitable for the study of electron-ion interactions, although the machine has been designed to be versatile and capable of performing a wide range of studies.

Since the magnets are located outside the vacuum vessel, the trap to window distance has been significantly reduced. Furthermore, the permanent magnets do not need to be continuous rings to produce the desired field. Accordingly, magnet rings are being fabricated to allow for detection of emitted photons at a range of angles (40^{o}-140^{o}) with respect to the electron beam propagation. The reconfigurable trap can accommodate in-situ detectors and in-line charged particle analysers including an in-line analyser to detect electrons resulting from various collision processes. In this way, electron energy loss spectroscopy may be performed on highly charged ion targets, giving rise to a new and complementary spectroscopic technique and providing a bridge between EBIT technology and traditional electron scattering techniques.

MACHINE DESIGN

Magnetic Structure

A pair of radially magnetized NbFeB ring magnets (one with a north pole on inner face, the other with the south pole innermost) are being used to provide the requisite magnetic field. Each of these magnets is mounted in a block of soft iron. Four 80mm diameter soft iron rods run from one soft iron block to the other to complete the magnetic circuit. The ring magnets have an outer diameter of 300 mm, an inner diameter of 130 mm, a length of 145 mm and a nominal separation of 122 mm. Our simulations show that this configuration gives rise to a peak field of about 0.65 Tesla at the trap centre and a corresponding beam diameter of about 100μm over a wide range of operating conditions [5].

Each magnetic ring is fabricated using 22 magnetized wedges and two non-magnetic wedges. The four non-magnetic wedges of the whole magnetic assembly (i.e. two ring magnets) lie in a horizontal plane containing the electron beam axis. As is shown in figure 1, this arrangement allows for detection of photons from a wide range of angles. Except for two small blind spots, photons can be detected at a range of angles from 40° to 140° with respect to the electron beam.

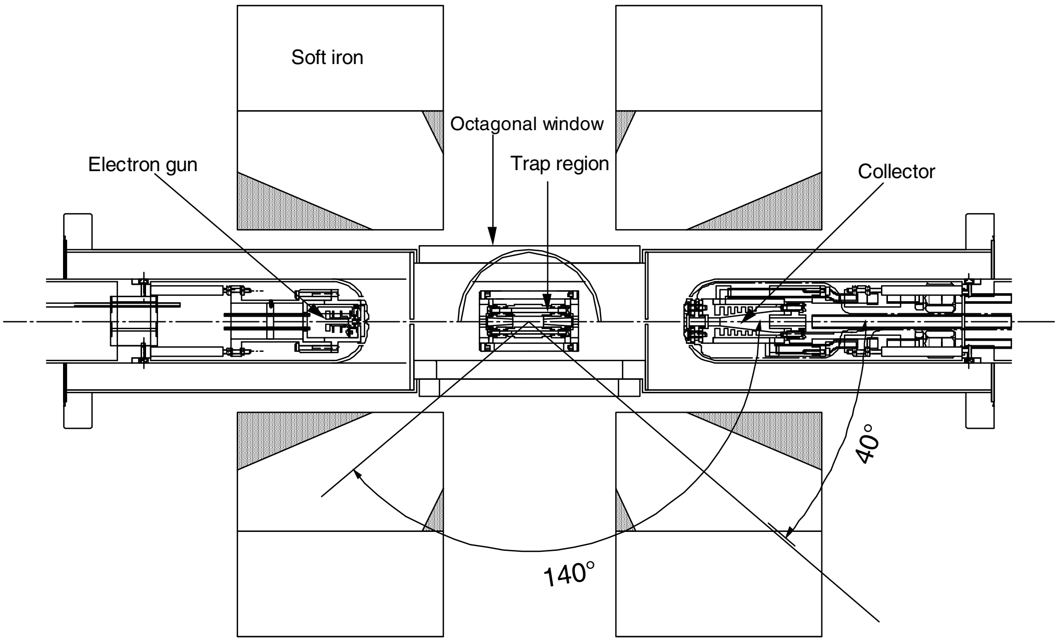

FIGURE 1. Overview of the new Belfast EBIT

Vacuum System

As with all EBITs, our machine has three main assemblies, the gun, the trap and the collector as is also shown in figure 1. The arrangement of these assemblies is such that the electron beam travels horizontally through a differentially pumped vacuum vessel. This vessel lies inside the bore of the two ring magnets. All vacuum components are based on the standard CF152 conflat flange size.

The central chamber is essentially a 4-way cross with special octagonal flanges machined onto the sides. The two side-arms of the cross contain the gun and collector assemblies with the trap sitting in the center of the cross. These side-arms are separated from the trap region by baffles containing small holes, through which the main electron beam passes. These baffles act to reduce the conductance from the electron gun and collector regions, each of which is pumped separately by its own turbomolecular pump. The top arm of the chamber is used for the trap's electrical and gas feedthroughs while a turbo-molecular pump, a bakeout lamp and a non-evaporative getter (NEG) pump are attached to the bottom arm.

The special side flanges are being used to allow for the maximum range of angles for light collection from the trap and also to allow convenient access to the trap so it can be reconfigured or various measurement instruments can be placed *in-situ*. These ports are situated either side of the trap as is shown in figure 1. The distance from the electron beam axis to the window is 5 cm. By using a recessed window, this distance can be reduced to 2.5 cm, giving a large solid angle for photon detection. Figure 2 shows a three dimensional representation of the centre of the chamber and the trap region.

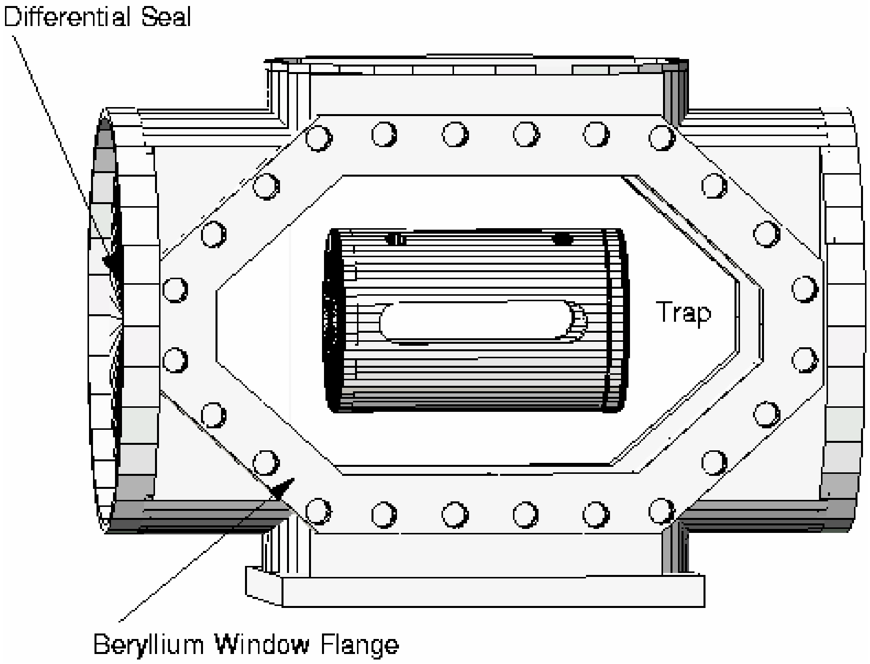

FIGURE 2. The central chamber trap housing, showing the trap location and one of the octagonal flanges designed to give maximum access to the trap.

Mechanical Support And Provision Of Services

The magnets are supported on a system of rails so they can be moved along the electron beam axis to facilitate baking of the central trap region and to give access to the trap region when changing the special octagonal flanges. Furthermore, each magnet may be moved independently so the magnet positions can be tuned empirically for best operation.

The electron gun and collector services are provided through two standard spherical 6-way crosses from which these assemblies protrude. Each cross provides access for electrical feedthroughs from above, pumping from below and for mechanical servicing, assembly and pressure measurement from the sides. Additionally, for the collector, water cooling is required. This is also provided from above. Each of these 6-way crosses is supported on a pair of rails so either the gun or collector can conveniently be withdrawn from the central chamber to allow for servicing.

Mechanical support for the electron gun, the trap and the collector assemblies is from above, on the flanges which provide the requisite electrical feedthroughs. High voltage isolators and x-y-z translators separate the feedthrough flanges from the main chamber. This arrangement allows each of these flanges and hence the assembly supported to float away from the main chamber potential (laboratory earth). In this manner, the gun and collector can be biased negatively with respect to laboratory earth while the trap can be biased either positively or negatively. That is to say, although much smaller, the machine has a super-EBIT type of configuration where both the gun and trap are independently floated. The x-y-z translators are situated on the chamber side of the isolators so the gun, trap and collector assemblies can be moved independently while the machine is in operation.

Electron Gun

The electron gun is a pierce type gun with a 3 mm diameter spherically concaved dispenser cathode. This gun is identical to the one used in the Tokyo-EBIT [6,7]. It is surrounded by a soft iron magnetic shield to make the magnetic field at the cathode surface as small as possible so as to obtain the highest compression of the electron beam [8]. The shape and position of the soft iron were carefully chosen to set the initial magnetic field gradient, to match the electron beam trajectories to the axial magnetic field [9,10].

Trochoidal Analyser

The first instrument we intend to put into the trap using the special octagonal ports is a compact trochoidal charged particle analyzer. Such analysers exploit the well known $\underline{E}\times\underline{B}$ cross-field drift. Because the drift velocity is given by

$$\underline{\mathrm{v}_d} = \left(\underline{E}\times\underline{B}\right)/B^2 \qquad (1)$$

for uniform fields, the total drift is independent of the charge of the particle being analysed. However, this drift is proportional to the time spent by a charged particle in the cross-field region so by use of acceleration between the trap and the analyzer, the total drift can be dependent on particle charge. These analyzers are time-of-flight for ions or equivalently axial momentum analyzers for electrons. Hence, depending on the voltages applied, the analyzer can be used to analyze either electrons or ions.

Initial simulations show that for near-threshold electrons (axial energy less than about 10eV), the analyzer has a 4π detection acceptance, along the length of the trap. Hence the analyzer is particularly sensitive for low energy electrons. Simulations for ions are still ongoing but initial results are encouraging suggesting the same analyzer, with different voltages applied to the electrodes, will be able to detect ions with a wide range of charges.

INITIAL EXPERIMENTS PROPOSED

Experiments Based On Photon Detection

As is summarized in figure 3, the new EBIT offers an unprecedented angular range of measurements. Indeed, many of the design choices have been made to ensure this is the case. Initial experiments will seek to take advantage of this feature. We will extend our ongoing program of dielectronic recombination (DR) measurements [11-14] by making measurements at 54^{o} to the propagation of the electron beam. At this angle, the second Legendre polynomial goes to zero for dipole transitions so a differential cross-section measurement is equivalent to a total cross-section measurement. Using this property absolute cross-sections and resonant strengths will be deduced free from any polarization correction. Furthermore, the angular dependence of photon emission will be measured to infer information about the polarization of transitions.

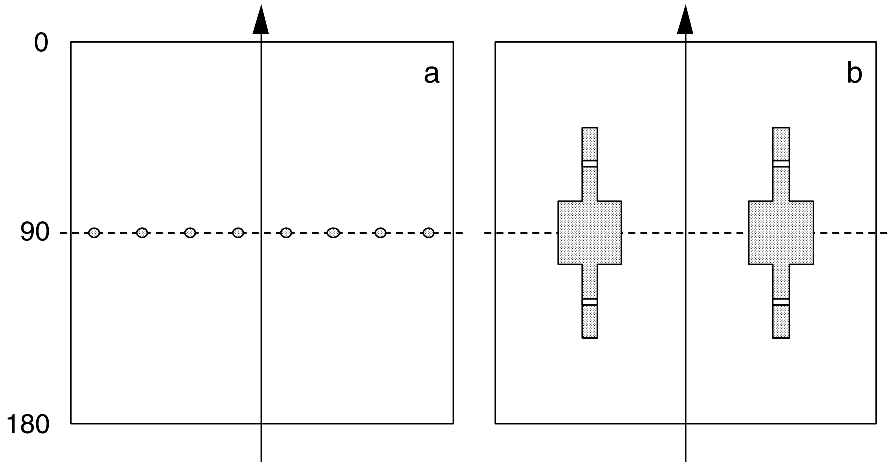

FIGURE 3. Representations of the range of angles over which x-rays can leave the trap to enter an x-ray detector; a) for a traditional EBIT, b) for the new Belfast EBIT. In each case, the vertical arrow represents the direction of propagation of the electron beam and the entire square represents the full

sphere (4π solid angle) around the trap. Polar angles with respect to the electron beam are represented by the vertical ordinate, azimuthal angles by the horizontal ordinate.

For single-detector experiments the physical environment is cylindrically symmetric about the electron beam axis. Hence, the wide range of azimuthal angles available only acts to provide the opportunity of measurement with increased sensitivity. However, for coincidence experiments or tomographic studies the range of azimuthal angles available with the Belfast EBIT open up interesting new possibilities.

Our recent studies of DR into hydrogen-like ions show that there are additional complexities when open-shell targets are under consideration, as compared to the more thoroughly studied closed shell systems [15]. As is illustrated in figure 4, formation of the resonance state (e.g. 2l2l'), the first decay (e.g. forming 1s2l') does not give rise to full stabilization. In general, a second photon is emitted; in this example the photon is due to the transition from 1s2l' to $1s^2$. Analogous processes can occur for DR into any target without a completely closed-shell. However, previous lack of detector access has made it impossible to do the coincidence measurements required to decouple the decay dynamics. Again, the unprecedented angular access will be of great benefit in this context. Indeed, for single-detector experiments, the wider range of azimuthal angles is of little benefit whereas for coincidence measurements this feature is of great benefit as pairs of detectors can be placed at many geometries of interest. Such measurements will form another part of the future experimental program.

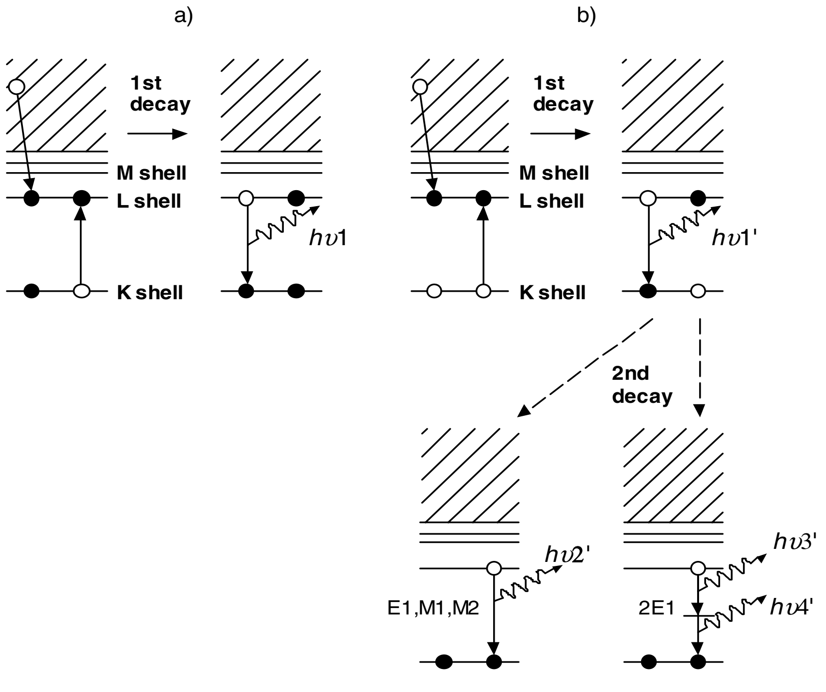

FIGURE 4. Comparison of the stabilization scheme for dielectronic recombination into a helium-like target a) to that for a hydrogen-like target b). Note that the creation of two 1s vacancies in the latter

case leads to much richer decay dynamics which can be expected to effect the energy balance of high temperature plasmas.

Experiments Based On Charged Particle Detection

The charged particle analysers currently under design will be mounted onto one of the special octagonal flanges, installed and used to measure product electrons. This will give rise to a new form of spectroscopy for highly charged ions. Complimentary to x-ray spectroscopy, this technique will be free from cascade effects. Due to sensitivity considerations and ease of operation, we will initially measure near-threshold electron spectra. This will be achieved by setting the analyzer to exclusively measure low energy electrons and monitoring their yield as the electron gun's energy is ramped.

In addition to electron detection, the analyser will be used to detect ions from the trap. This detection will occur without loss which normally occurs in EBITs due to the ions passing through the collector. It is hoped that this will lead to more representative sampling of ions of different charge states in the trap region. Hence, it will be possible to infer electron impact ionisation cross-sections from rates of creation and equilibrium charge balances of neighbouring states. In this manner, electron impact ionisation cross-sections will be measured for a wide range of few-electron highly charged ions.

CONCLUSION

Subassemblies of the new machine are currently being constructed prior to full assembly and testing in a new International Research Centre for Experimental Physics (IRCEP) [16]. This centre has been founded specifically to encourage interdisciplinary experimental physics. The machine will be housed in a purpose built ion hall along with electron cyclotron resonance (ECR), matrix assisted laser deposition (MALDI) and other ion sources. Within the ion hall, the machine is being located in a light-tight room with all operating consoles being outside this room. Furthermore, the extraction line of the machine will take ions from the light-tight room out into the main ion hall for various ion-matter interaction experiments.

Although several of the machine's features have been designed specifically for studies of electron-ion interactions, it is hoped that a full research program can be developed using both ions inside the machine's trap and also ions extracted from the machine. Indeed, the inherent versatility in the design, its location within the IRCEP and the associated visitor program [16] mean that the new EBIT can be used by many different scientists for a wide range of experiments. People interested in using the machine are encouraged to contact the e-mail address given above.

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REFERENCES

1. E. D. Donets, V. I. Ilushchenko and V. A. Alpert, in: Proc. of the Premiere Conf. sur les Sources d'Ions, Saclay, France 1969, pp. 625.
   E. D. Donets and V. P. Ovsyannikov, Sov. Phys. JETP **53**, 466 (1981).
2. M. A. Levine *et al.*, Phys. Scr. **T22**, 157 (1988).
3. V. P. Ovsyannikov and G Zschornack, Rev. Sci. Instrum. **70**, 2646 (1999).
4. K. Motohashi *et al.*, Rev. Sci. Instrum. **71**, 890 (2000).
5. H. Watanabe, B.E.O'Rourke and F.J. Currell, Rev. Sci. Instrum. *in press* (2004).
6. F.J.Currell *et al.*, J.Phys.Soc.Jpn. **65** 3186 (1996).
7. H.Watanabe, *et al.*, J.Phys.Soc.Jpn.**66** 3795 (1997).
8. G. J. Hermann, Appl. Phys. **29**, 127 (1958)
9. G. R. Brewer, Focusing of Charged Particles, Vol. 2, Academic Press, New York, edited by A. Septier, 1967, p73.
10. R. Becker, Nucl. Instrum. and Methods **187**, 255 (1981).
11. H. Watanabe *et al.*, J.Phys.B. **34**, 5095 (2001).
12. B.E. O'Rourke *et al.*, Nuc.Instr and Meth. B. **205**, 378 (2003).
13. Y. Li *et al.*, J. Plasma and Fusion Res. **79**, 52 (2003)
14. A.V. Korol, F.J. Currell and G.F. Gribakin., J.Phys.B. *submitted* (2004).
15. H. Watanabe *et al.*, Phys.Rev.Lett. *submitted* (2004).
16. http://143.117.13.2/school/ircep/