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The Toledo heavy ion accelerator

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The recently installed 330 kV electrostatic positive ion accelerator at the University of Toledo is described. Experiments have been performed using ions ranging from H^+ to Hg^{2+} and exotic molecules such as HeH^+. Most of these experiments involve the beam–foil studies of the lifetimes of excited atomic states and the apparatus used for these experiments is also described. Another beamline is available for ion-implantation. The Toledo heavy ion accelerator facility welcomes outside users.

1. Introduction

The Toledo heavy ion accelerator, THIA, is a 330 kV positive ion accelerator that is installed in McMaster Hall 1019 on the campus of the University of Toledo. Along with other applications, the THIA facility was designed to allow experimenters to study the properties of excited electronic states in atoms and ions using the beam–foil technique [1]. In this technique, excited levels in neutrals, singly charged and doubly charged ions are created by passing the energetic ion beam through a thin carbon foil. Electrons may be captured or lost while the ions from the beam are in the foil, and additional electrons may be captured while the ions are exiting the foil. After this electronic rearrangement the ion is frequently in an excited state. This excited state may decay by the emission of a photon which can be detected and used to gain insight into the excited level.

The accelerator is a variant of the Cockcroft–Walton electrostatic design with the high voltage provided by a switching high voltage supply with ripple suppression. An electrostatic switchyard is used to direct the beam into one of three beamlines. Installed on the right beamline is the beam–foil chamber containing a

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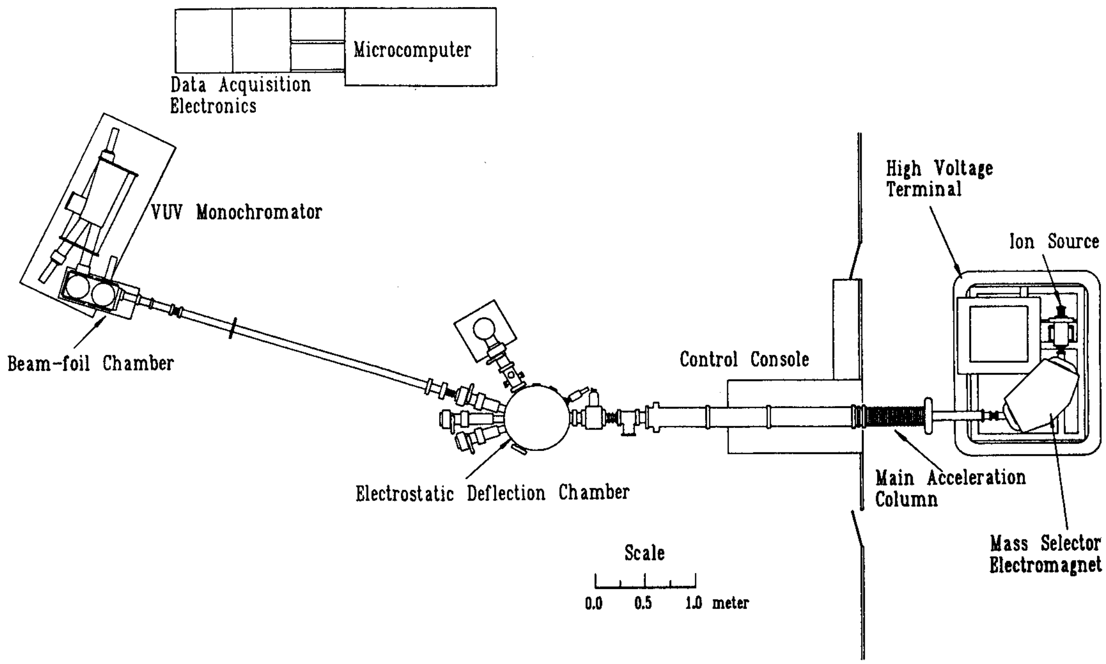

Fig. 1. A schematic of the general layout of the Toledo heavy ion accelerator facility, THIA.

mechanism for holding and translating foils parallel to the axis of the ion beam and an attached vacuum ultraviolet monochromator. The center beamline is set up to allow for ion implantation. The general layout of the THIA facility is shown in fig. 1.

2. The heavy ion accelerator

The accelerator is a Danfysik [2] model 1080–150 with the maximum terminal voltage upgraded from 120 kV to 300 kV. The ion source, the initial acceleration (0–30 kV), a focusing element, the mass analyzing magnet, and the associated support electronics all operate at this terminal voltage. Power is provided to the components by a motor-generator set with the generator also at terminal voltage. A relatively small mass analyzing magnet is adequate because mass analysis is preformed before the main acceleration.

Central to the upgrade of THIA was the installation of a Glassman High Voltage Inc. [3] model P0300P001-LR high voltage supply. This unit employs a double-cascade voltage multiplier that is similar to a Cockcroft–Walton. This high voltage supply is rated at 1 mA of current for voltages from 0 to +300 kV, with line regulation of $\pm 0.005\% \pm 1$ V and a 7.5 V ripple. In addition to the new power supply the upgrade required raising the terminal for greater electrical insulation and installing a longer acceleration column.

The ion source used at THIA is Danfysik [2] model 911A that is based on the hollow cathode design developed at the Niels Bohr Institute by G. Sidenius. In this compact source, electrons from the filament/cathode assembly are accelerated toward the anode and the source material is ionized in a discharge between the anode and the cathode and extracted through the hollow cathode. In addition to gases, solids may be used as the source material because the source includes an oven capable of reaching 1700°C, thus allowing ions of almost any element to be created and used for experiments. Table 1 contains a list of some of the ions produced at THIA.

The gas feed to the ion source has been modified to allow the introduction of gas from two gas bottles at the same time. To accomplish this, a second leak valve was installed by placing a tee in the original gas feed line between the ion source and the original leak valve. Both high pressure sides of both leak valves were connected to gas bottles at ground potential by plastic feed lines and regulators. By using both leak valves the production exotic molecular ions such as HeH^+ can be optimized by controlling the gas mixture. When methane (CH_4) was used alone as a source gas for C^+ ions, the ion source quickly fouled with carbon, but this could be avoided by using argon as a support gas. The source was started with pure argon and when the ion source stabilized, a small flow of methane was leaked into the source with the argon and a stable C^+ beam was obtained.

Table 1
Some of the ions used at the Toledo heavy ion accelerator facility

Ion	Current (μA)	Source material	Support gas
H^+	1.5	H_2	Ar
H_2^+	1.7	H_2	Ar
H_3^+	0.25	H_2	Ar
He^+	6	He	
HeH^+	0.5	He, H_2	
Li^+	8	LiCl	Ar
Be^+	1.4	Be	Ar
C^+	0.1	CH_4	Ar
CO^+	6	CO_2	
N^+	2	N_2	
O^+	2	CO_2	
O_2^+	3	CO_2	
$(^{20}Ne)^+$	90	Ne	
$(^{22}Ne)^+$	8	Ne	
Si^+	0.5	Si	Ar
P^+	10	P	
S^+	0.7	S	Ar
Cl^+	0.2	NaCl	
Ar^+	12	Ar	
K^+	17	KI	
Ca^+	5	Ca	He
Ca^{2+}	0.01	Ca	He
Zn^+	0.1	Zn	
Au^+	0.1	Au	Ar
Hg^+	0.2	HgO_2	Ar

After acceleration the beam may be focused and steered before entering the switchyard that consists of a pair of electrostatic deflection plates. The center beam line is set up for ion implantation. An electrostatic energy analyzer is available to measure the energy of the ions [4]. The right beam line is dedicated to beam–foil spectroscopy.

3. The beam–foil chamber and monochromator

In its simplest form, beam–foil techniques consist of passing a fast ion beam through a thin foil during which time the ions may experience charge exchange or excitation. After exiting the foil, the ions decay to a lower energy level by emitting photons that are detected. Since the beam is nearly monoenergetic, the time between excitation in the foil and decay by photon emission is proportional to the distance that an ion has traveled from the foil before it decays. Thus the apparent lifetime of an excited atomic state can be determined by measuring the intensity of light at the wavelength of the emitted photons as a function of the distance after the foil. A particular excited energy level is selected for study by using a spectrometer to pass only the photons whose wavelength is associated with the decay of this selected level and then varying the distance downstream of the foil that is being viewed.

The spectrometer used for beam–foil studies at THIA is an Acton Research Corp. [5] model VM-521-SG 1 m vacuum monochromator. The entrance optical axis is set at a right angle to the path of the ion. The optical system is a 15° normal incidence mounting of a concave grating, with an aperture ratio of $f/10.4$ for a 96 mm wide grating. With a 2400 groove/mm grating the maximum resolution is 0.007 nm (at 160 nm). A computer controlled stepping motor connected to an external lead screw is used to select the passed wavelength. External control of the spectrometer's sine bar allows for refocusing to a moving light source [6]. At THIA, gratings are available for use in the range of 50–650 nm. Either of two mounted gratings can be selected for use by an external lever. The typical operating vacuum for this system is below 1×10^{-6} Torr.

The monochromator was modified to allow the entrance slits to sit inside the beam–foil chamber so that the slits are close to the ion beam. The beam–foil chamber consists of a locally manufactured high vacuum enclosure and an assembly to hold a foil and translate it parallel to the path of ion beam and thus vary the time after excitation that is being viewed. Foils are mounted on a foil wheel and the foil wheel assembly is translated by a 32 thread per inch lead screw. This lead screw is driven by an external stepping motor through a 40 tooth driving gear and a 120 tooth driven gear. For a 1.8° step of the motor the foil is translated 0.0013 mm. The foil wheel is rotated about an axis parallel to the path of the beam, to place one of the 23 mounted foils or the one blanked position into the beam's path. This allows the experimenter to replace a broken foil quickly.

4. Conclusions

A wide range of ions and energies is available at THIA for a variety of atomic physics studies. The lifetimes of excited states in neutral atoms and singly charged or doubly charged ions have been studied at THIA. Targets for nuclear physics experiments have been prepared using ion implantation of isotopes such as ^{22}Ne. Outside users are welcome at the Toledo heavy ion accelerator (THIA) facility.

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