

# Heavy ion acceleration at ORIC\*

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## ABSTRACT

Microampere beams of 4+ ions of  $^{12}\text{C}$ ,  $^{16}\text{O}$ , and  $^{14}\text{N}$  are now accelerated in the Oak Ridge Isochronous Cyclotron from a heated-filament ion source of conventional dimensions. Small beams of  $^{13}\text{C}^{4+}$  (from natural carbon) and  $^{20}\text{Ne}^{5+}$  have also been obtained. The intensity of these heavy ion beams is strongly dependent on arc power. A water-cooled copper arc chamber and an insulated anti-cathode are used. Up to 1.5 kW can be dissipated in the arc. Studies of pressure attenuation of the beam show a factor of 2 loss for a path length of 650 m at a pressure of  $\sim 3 \times 10^{-6}$  torr. Good pressure is maintained by cryopumping at liquid nitrogen temperature adjacent to the circulating beam.

## 1. INTRODUCTION

The original design of ORIC included provisions in magnetic field and frequency for heavy ion acceleration. At the time that ORIC was started, however, the pressure of doing experiments with light ions did not permit the allocation of time to develop a suitable heavy ion source and appropriate operational techniques. Heavy ion experiments at ORNL were thus discontinued when the 63-in, 27-MeV nitrogen cyclotron was shut down in 1962. In 1968, renewed interest in heavy ion experiments in both chemistry and physics motivated an intensive effort to develop usable heavy ion beams. Several heavy ion beams are now available, see Table 1. One experiment using heavy ions from ORIC will be described in the conference next week.<sup>1</sup> The most useful beams, where the energy exceeds the Coulomb barrier, can be achieved in ORIC with a  $q/A \geq 0.25$  for heavy element targets. Not all the beams listed in the table

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Table 1. HEAVY IONS AVAILABLE AT ORIC

Ion*	Harmonic	Energy (MeV)		Extracted Beam ( $\mu$ A)	Source Power (W)
		Achieved	Design Max.		
$^{12}\text{C}^{3+}$	3	49-58	75	1.5	600
$^{12}\text{C}^{4+}$	1	100-120	134	15.0	1200
$^{13}\text{C}^{4+}$	1	127	145	0.005	1325
$^{14}\text{N}^{4+}$	1	103-107	114	0.3	750
$^{16}\text{O}^{4+}$	3	67-77	100	3.0	> 1700
$^{20}\text{Ne}^{5+}$	3	92	123	$\sim$ 0.001	$\sim$ 1000

\*From non-enriched source materials

have been used in experiments. More effort has been placed on the  $^{12}\text{C}^{4+}$  beam than on any other, and at the present it is the largest and most used.

## 2. HEAVY ION SOURCE

For heavy ions the original ORIC source was modified to operate at greater intensity, though the basic dimensions are the same, Fig. 1. A water-cooled copper arc chamber is used in place of the original graphite chamber. The ion extraction slit is tantalum and is replaceable. The filament is 0.170 in. in diam., and the insulated anti-cathode is, in most cases, a graphite button. Source gas

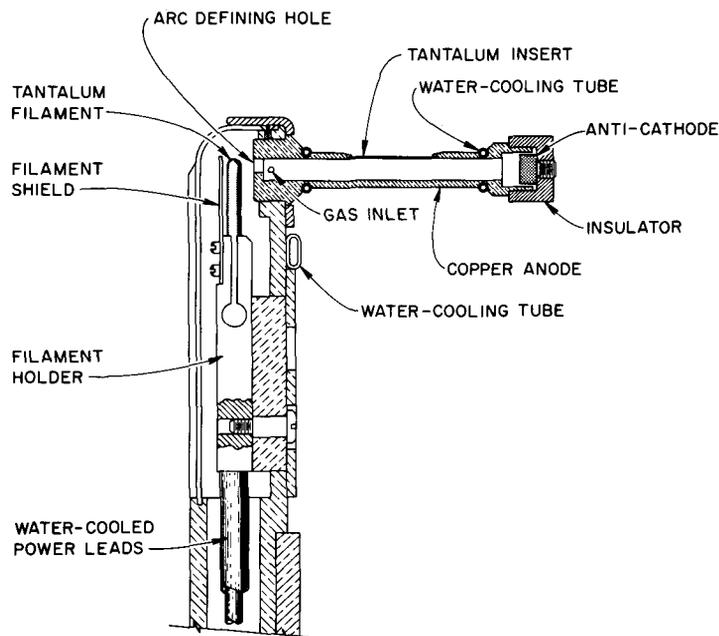


Fig. 1. ORIC heavy ion source

is admitted directly to the arc chamber at the filament end. The arc defining hole is  $\frac{3}{16}$  in. in diameter with a length of  $\frac{1}{8}$  in. Variations of this source have been tried, but most of the source dimensions appear to be non-critical.

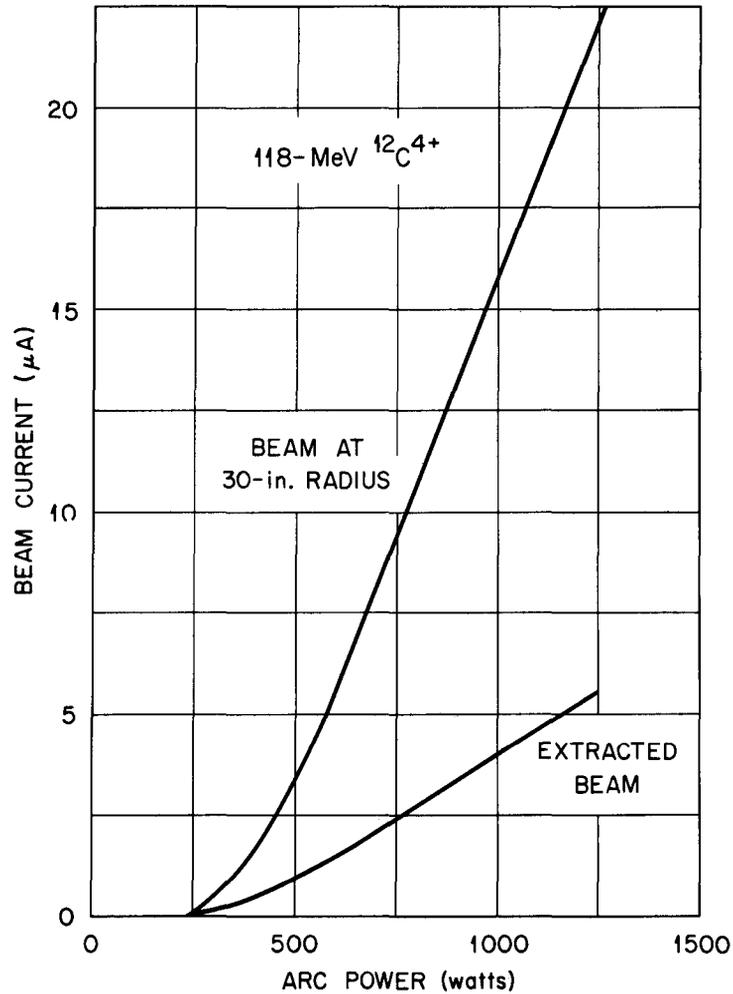


Fig. 2. Internal and extracted beam currents vs arc power

The important conditions for high output with this source are the pressure in the arc chamber (gas flow rate) and the arc power. Also, over a limited range, the ion output is approximately proportional to the area of the ion extraction slit. The largest slit we have used is  $\frac{1}{2}$  in  $\times$   $\frac{3}{16}$  in. Data taken during a recent cyclotron run are shown in Fig. 2. The arc potential was held constant at 250 V, and the current was varied. The source gas flow was approximately optimised at 1 cm<sup>3</sup>/min; however, very small changes in gas flow can easily make a factor of 2 difference in beam for the same arc power.

It was observed that as the arc power is increased a point is reached where

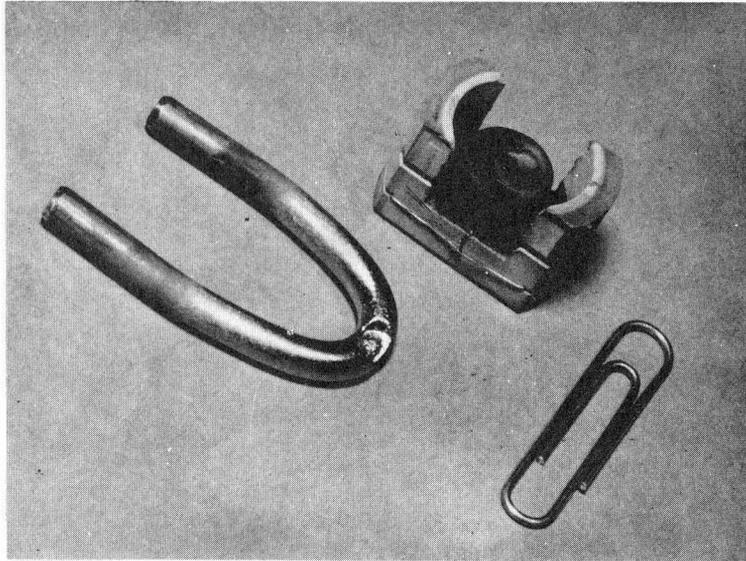


Fig. 3. Filament and insulated anti-cathode as eroded by three hours of operation at about 1 kW. The tantalum wire prevents the insulator from coming apart during operation if it cracks due to thermal stress

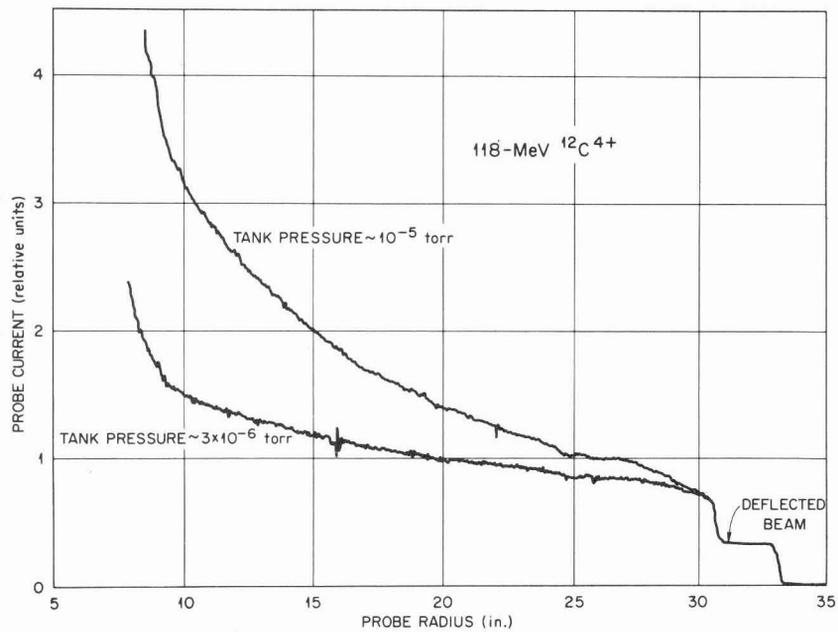


Fig. 4. Beam current vs radius for a  $^{12}\text{C}^{4+}$  beam at two tank pressures

the beam current falls rapidly to zero; although the voltage and current appear normal, there is no longer an arc visible through the ion extraction slit. This is interpreted as the establishment of an arc in another part of the source assembly, but this has not been verified.

At about 1 kW arc power the average life of the source is 4 to 5 h; one source ran 7 h. The filament is usually the first component to fail; however, reduced resistance between the insulated anti-cathode and ground as indicated by a significant reduction in beam is sometimes the failure mechanism. The ion erosion pattern in both the filament and the anti-cathode button after about 3 h can be seen in Fig. 3.

### 3. ANTI-CATHODE MATERIALS

The ORIC heavy ion source produces a much more intense carbon beam than any other beam, probably because the anti-cathode button material is graphite. If oxygen source gas is used with a graphite anti-cathode, more  $^{12}\text{C}^{3+}$  is produced than  $^{16}\text{O}^{4+}$ . If the cyclotron is well tuned and operating stably, the two peaks can be resolved. When a tantalum anti-cathode is used, an oxygen beam that is free of carbon contamination can be readily obtained. The beam output and source life with a tantalum anti-cathode are limited by the melting point of the anti-cathode insulator, and by buildup of sputtered tantalum.

In a preliminary test with a boron nitride anti-cathode, the  $^{14}\text{N}^{4+}$  beam intensity was increased by an apparent factor of about 3 (with nitrogen source gas). No boron beam was detected in this first test. There were no problems with establishing a good arc with the non-conducting anti-cathode, and a normal heavy ion erosion pattern was formed.

### 4. PRESSURE EFFECTS

Curves of beam current vs radius for two tank pressures are shown in Fig. 4. The beam travels about 650 m from the 12.5 in radius to extraction, requiring

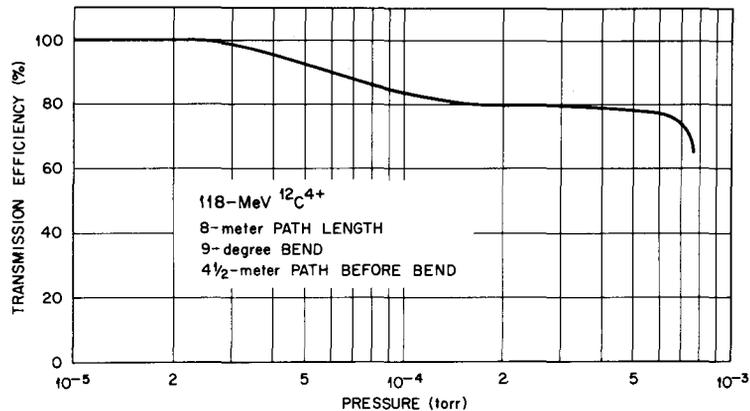


Fig. 5. Beam attenuation due to charge exchange vs pressure in an external beam pipe with bending magnet

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$\sim 20 \mu\text{s}$ . When the tank pressure is  $3 \times 10^{-6}$  torr the attenuation factor is 2 for this path length, and when the tank pressure is  $10^{-5}$  torr the attenuation factor is 3.6. In the low pressure case there is good agreement with the Cole-Main<sup>2</sup> formula for beam loss.

$$n/n_0 = \exp(-10^{10} Pt) \quad P \text{ in torr, } t \text{ in s.}$$

In the case of higher pressure, however, our attenuation measurements are lower than the predicted loss by a factor of about two. The pressures are quoted for the centre of the tank; the service ion gauge normally reads considerably lower. To aid in reducing the pressure in the region where the beam is accelerated, liquid nitrogen is circulated through a coil of copper tubing located about 6 cm from the median plane. The cold surface area is 0.5 m<sup>2</sup>.

The pressure in the external beam pipe is normally maintained below  $10^{-5}$  torr and beam loss is negligible for reasonably short distances. The effect of increasing the pressure in the external beam line is shown in Fig. 5. At 2 to  $3 \times 10^{-5}$  torr, charge exchange begins to occur along the 4.5 m path ahead of the magnet and beam is lost in the bending process. At  $7 \times 10^{-4}$  torr the 4+ beam starts to disappear much more rapidly.

## 5. ANALOG BEAMS

Tuning the cyclotron magnetic field and extraction system for a beam with the same  $q/A$  as the desired heavy ion beam has proved to be a useful technique when developing new beams. This, in effect, separates the problem of obtaining correct acceleration and extraction conditions from the problem of obtaining optimum source conditions. It is particularly valuable if the life of the source is short. For example,  $^4\text{He}^+$  was used as an analog for  $^{16}\text{O}^4$ ,  $^{12}\text{C}^{3+}$ , and  $^{20}\text{Ne}^{5+}$ , and  $^3\text{He}^+$  for  $^{12}\text{C}^{4+}$ . After the proper source operating conditions are well defined this technique is no longer necessary.

## 6. FUTURE DEVELOPMENTS

In October of this year an axial injection channel will be installed for the polarised ion source. This will permit the future use of an external heavy ion source capable of greater arc power and hence greater beam intensity. We anticipate that an external source will also have substantially longer life. For long runs multiple sources could be used.

## REFERENCES

1. Mallory, M. L., *et al*, Nuclear Chemistry with the Oak Ridge Isochronous Cyclotron, Proceedings of the International Conference on the Uses of Cyclotrons in Chemistry, Metallurgy, and Biology, Oxford, England, September 22, 23, 1969, p. 42.
2. Cole, F. T. and Main, R. M., Proceedings of the Sixth International Conference on High-Energy Accelerators, 1967, CEAL-2000, 18-26 Cambridge, Mass.